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Causal Factors and Adverse Conditions of Aviation Accidents and Incidents Related to Integrated Resilient Aircraft Control

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Summary

The causal factors of accidents from the National Transportation Safety Board (NTSB) database and incidents from the Federal Aviation Administration (FAA) database associated with loss of control (LOC) were examined for four types of operations (i.e., Federal Aviation Regulation Part 121, Part 135 Scheduled, Part 135 Nonscheduled, and Part 91) for the years 1988 to 2004. In-flight LOC is a serious aviation problem. Well over half of the LOC accidents included at least one fatality (80 percent in Part 121), and roughly half of all aviation fatalities in the studied time period occurred in conjunction with LOC.

In about 30 percent of Part 121 LOC accidents, the LOC was secondary to a system/component failure/malfunction (SCFM), compared with 8 to 12 percent of the accidents in other flight operation categories. The most frequently cited components and systems were the engine and flight control system. Twenty-three percent of the Part 121 LOC accidents were secondary to aircraft damage (most often due to fire), compared with 3 to 8 percent of the accidents in other flight operation categories. As a result, for roughly 35 percent of the LOC accidents in Part 121, aircraft control was not possible, compared with 6 to 9 percent of the accidents in other flight operation categories. In flights other than Part 121, 25 to 40 percent of the LOC was caused by inadequate airspeed leading to an inadvertent stall. Icing (both preflight and in-flight) and adverse winds were the primary cause of a large number of accidents. Other frequently cited causes for LOC are inadequate preflight, improper planning or decisions, and flying in obscuration or at night. The accidents and incidents were divided into three groups: LOC secondary to SCFM, LOC secondary to aircraft damage, and LOC due to control upset.

The Aviation Safety Reporting System (ASRS) incident database was examined for three types of operation (Part 121, Part 135, and Part 91) for the years January 1993 to May 2008. From the analysis of this data, five aircraft systems have been identified as critical in regards to the frequency of incidents they represent. These systems are landing gear, brakes, air flight control, propulsion systems, and control surfaces.

Most accidents and incidents have more than one causal factor cited by accident and incident investigators.

An adverse events table was updated to provide focus to the technology validation strategy of the Integrated Resilient Aircraft Control (IRAC) Project. The table contains three types of adverse conditions: failure, damage, and upset. Thirteen different adverse condition subtypes were gleaned from the ASRS, the FAA Accident and Incident database, and the NTSB database. The severity and frequency of the damage conditions, initial test conditions, and milestones references are also provided.

1.0 Introduction

1.1 Purpose of Study

NASA's Integrated Resilient Aircraft Control (IRAC) Project is one of four projects within the Agency's Aviation Safety Program (AvSafe) in the Aeronautics Research Mission Directorate (ARMD). The IRAC Project, which was updated April 13, 2007, conducts research to advance the state of the aircraft flight control to provide onboard control resilience for ensuring safe flight in the presence of adverse conditions (faults, damage, and upsets). Adverse events include loss of control (LOC) caused by environmental factors and actuator and sensor faults or failures, and will expand toward more complicated damage conditions (Ref. 1).

The purpose of this study is to review statistical data and literature from academia, industry, and other Government agencies to interpret and extract information about causal factors for aircraft incidents and accidents that are related to the key research areas in IRAC. From this information, a list of potential adverse conditions and initial test conditions was established against which IRAC technologies can be evaluated (Ref. 1). Outcomes of this study include

(1) A report that documents causal factors related to LOC gleaned from the analysis of the incidents and accidents related to IRAC.
(2) A list of potential adverse conditions and initial test conditions against which flight, propulsion, and mission adaptive control approaches can be evaluated.

The results of this study are considered a "waypoint" to establish future requirements for the project.

1.2 Overview of Study Contents

The expected outcomes for this study are addressed in sequential order. Outcome 1 is addressed in the NASA Analyses of National Transportation Safety Board (NTSB) Accident Data and Federal Aviation Administration (FAA) Incident Data as well as the NASA Analysis of Aviation Safety Reporting System (ASRS) Incident Data sections. Outcome 2 is the focus of the adverse conditions table section. Finally, discussion and the conclusions that have been drawn are provided. Appendix A lists the acronyms used in this report and their definitions, and Appendix B presents accidents for Part 121 and Scheduled Part 135 flight operations that were determined to include in-flight LOC.

2.0 NASA Analysis of National Transportation Safety Board and Federal Aviation Administration Accident and Incident Data

The first expected outcome of this study is a report that documents the results of an examination of the most recent statistical and prognostic incident and accident data that is available to determine the causal factors related to LOC in U.S. commercial aviation accidents and incidents. This section contains the results of two separate statistical analyses that have been conducted by NASA to address this expected outcome. The first statistical analysis examined publicly available NTSB and FAA accident and incident data. A second statistical analysis was conducted using ASRS reports as the data source. All of these data sources can be accessed using the FAA's Aviation Safety Information Analysis and Sharing (ASIAS) System (Ref. 2).

In-flight loss of aircraft control contributed to less than 20 percent of U.S. aviation accidents between 1988 and 2004, but these accidents were responsible for more than half of the aviation fatalities during that time period. The current analysis has examined the causes of LOC events across a 17-yr span (1988 to 2004) within the four categories of operation (Part 121, Scheduled Part 135, Nonscheduled Part 135, and Part 91). In this analysis, "commercial" is defined as Part 121, Scheduled Part 135, and Nonscheduled Part 135 flights. Part 121 operations applies to major airlines and cargo carriers that fly large transport-category aircraft, and Part 135 applies to commercial aircraft air carriers commonly referred to as commuter airlines. Prior to March 1997, Part 121 operations included aircraft with 30 or more seats. In March 1997, the definition of Part 121 operations changed and now includes those aircraft with 10 or more seats. Scheduled operation refers to "any common carriage passenger-carrying operation for compensation or hire conducted by an air carrier or commercial operator for which the certificate holder or its representative offers in advance the departure location, departure time, and arrival location" (Ref. 3). A nonscheduled operation refers to "any operation for compensation or hire in which the departure time, departure location, and arrival location are specifically negotiated with the customer." Part 91, also known as general aviation, refers to all aviation other than commercial (Ref. 3). The word "event" is used here to encompass both accidents and incidents that are defined as follows (Ref. 4):

Accident an occurrence associated with the operation of an aircraft, which takes place between the time any person boards the aircraft with the intention of flight and all such persons have disembarked, and in which any person suffers death or serious injury, or in which the aircraft receives substantial damage.

Incident an occurrence other than an accident, associated with the operation of an aircraft, which affects or could affect the safety of operations.

The source for accident data is the NTSB Aviation Accident and Incident Data System, and the source for incident data is the FAA's Accident/Incident Data System. Although both databases contain both accident and incident data, the FAA has primary investigative responsibility for incidents and the NTSB is the authority for accident investigation. Appendix B lists all the accidents for Part 121 and Scheduled Part 135 flight operations that were determined to include in-flight LOC in this study.

The accident data have previously been classified using the Commercial Aviation Safety Team/International Civil Aviation Organization (CAST/ICAO) Common Taxonomy Team (CICTT) accident category taxonomy (Ref. 5). This taxonomy delineates LOC as being in-flight or on-ground. In-flight LOC was subsequently partitioned by general phase of flight (i.e., takeoff, approach/landing, or en route).

Selection of LOC events from the incident data was accomplished using two methods. First, if in the data record, "FLTCNTL/AIR" was a primary or secondary cause, and second, if the words "control," "stall," or "spin" were found in the narrative text. All of these records were reviewed; more than 95 percent were excluded. In a large percentage of the records with the word "control" in the text, that word was used in the context of specific flight controls, traffic control, or command of the aircraft (e.g., "the first officer was at the controls"). These were excluded, as were those involving on-ground or ground-effect LOC. Ground-effect LOC includes runway contact events (hard or bounced landings or wing, propeller, or tail strikes), undershoots, overruns, and runway excursions, and collisions with runway signs, markers, or lights. Essentially, the incidents included in this analysis occurred after flight was established in the takeoff climb and prior to the landing flare or during an aborted landing. This is consistent with the accident taxonomy.

A summary of the number of LOC events can be found in Table 1. Data for total flight hours were obtained from tables published by the NTSB, which they based on data from the FAA. In Part 121 flights, LOC contributed to only 4 percent of all accidents, but 34 percent of fatal accidents, and 55 percent of all fatalities. Eighty percent of the LOC accidents were fatal. Fifty-seven percent of Part 91 fatalities (and 55 percent of fatal accidents) were attributed to loss of aircraft control, and 53 percent of the LOC accidents were fatal. Among Part 135 accidents, LOC accounted for 15 to 18 percent of all accidents, 39 to 44 percent of fatal accidents, and 41 to 49 percent of all fatalities. Sixty to sixty-four percent of Part 135 LOC accidents were fatal.

TABLE 1.—SUMMARY OF LOSS OF CONTROL (LOC) EVENT CHARACTERISTICS BY OPERATION CATEGORY

Type of events	Operation category				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Total flight hours	251,751,143	25,353,146	49,588,000	441,207,000	767,896,289
Total accidents	630	217	1115	24,473	26,435
LOC accidents	26 (4% of total accidents)	32 (15% of total accidents)	198 (18% of total accidents)	4961 (20% of total accidents)	5217 (20% of total accidents)
LOC accidents per million flight hours	0.10	1.26	4.03	11.24	6.79
Fatal accidents	62 (10% of total accidents)	49 (23% of total accidents)	293 (26% of total accidents)	4815 (20% of total accidents)	5289 (20% of total accidents)
Fatal LOC accidents	21 (81% of LOC accidents)	19 (59% of LOC accidents)	128 (65% of LOC accidents)	2635 (53% of LOC accidents)	2803 (54% of LOC accidents)
Total fatalities	2165	328	698	9146	12,337
Fatalities in LOC accidents	1186 (55%)	161 (49%)	285 (41%)	5178 (57%)	6810 (55%)
Total incidents	7808	2234	2201	29,520	41,763
LOC incidents	38	5	8	81	132
LOC incidents per million flight hours	0.151	0.197	0.161	0.18	0.17

In-flight LOC was considered a factor in less than 0.5 percent of all incidents. Twenty-nine percent of the LOC incidents occurred in Part 121 flights, and 61 percent were in Part 91. Part 121 is the only flight category with more LOC incidents than accidents. Outside of transport category aircraft, LOC is likely to result in a level of aircraft damage that will cause the event to be considered an accident, rather than an incident. In most of these incidents, control of the aircraft was regained prior to a collision with terrain or objects.

Since 1988, there have been no more than eight LOC events each year in Part 121 flights, and about 60 percent of those were incidents (see Fig. 1). From 1997 to 2004, there were a total of 7 LOC accidents and 21 incidents.

With the exception of 1992, there have been no more than five LOC events each year in Scheduled Part 135 flights, but about 82 percent of the events were accidents (see Fig. 2). Seventy percent of the events occurred prior to 1997.

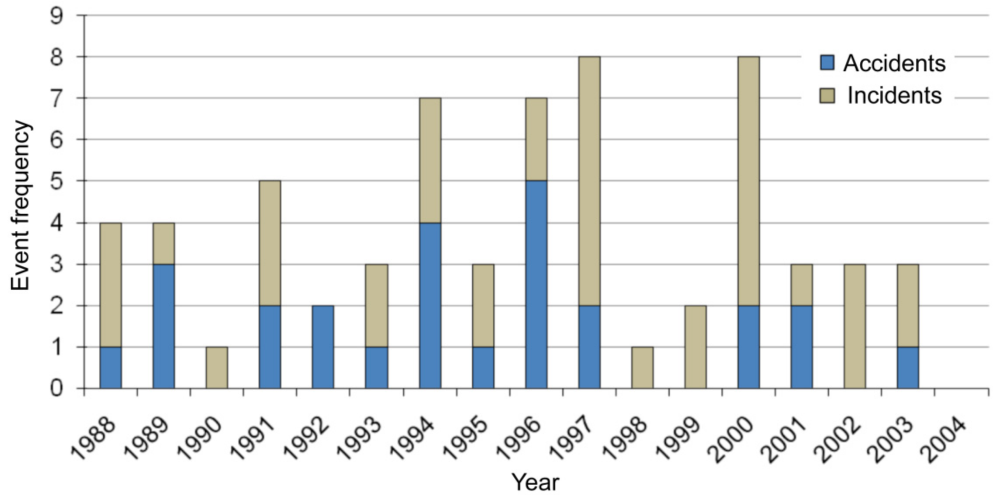

Figure 1.—Frequency of Part 121 loss of control events per year.

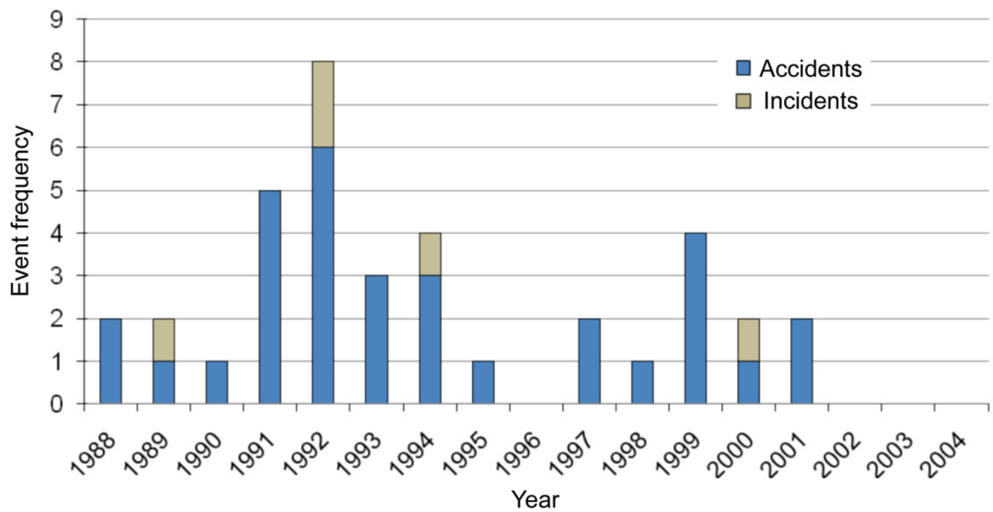

Figure 2.—Frequency of Scheduled Part 135 loss of control events per year.

Between 1988 and 2004, there were no more than 16 LOC events each year in Nonscheduled Part 135 flights (see Fig. 3). The number of events has been generally decreasing over time, with a slight bump in 2004.

LOC events in Part 91 have declined dramatically from 1988 to 2004 (see Fig. 4), but there are still more than 200 events each year. Nearly all of the Part 91 LOC events are considered accidents.

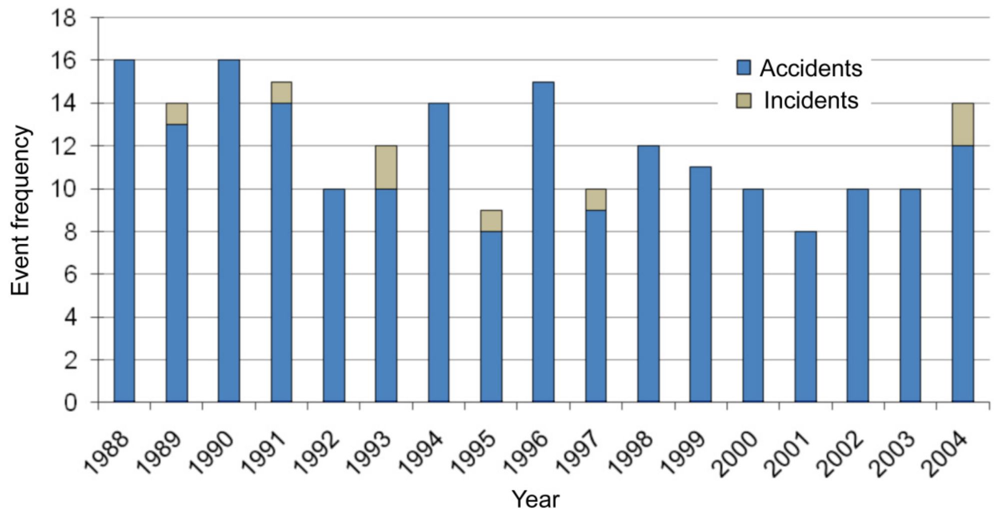

Figure 3.—Frequency of Nonscheduled Part 135 loss of control events per year.

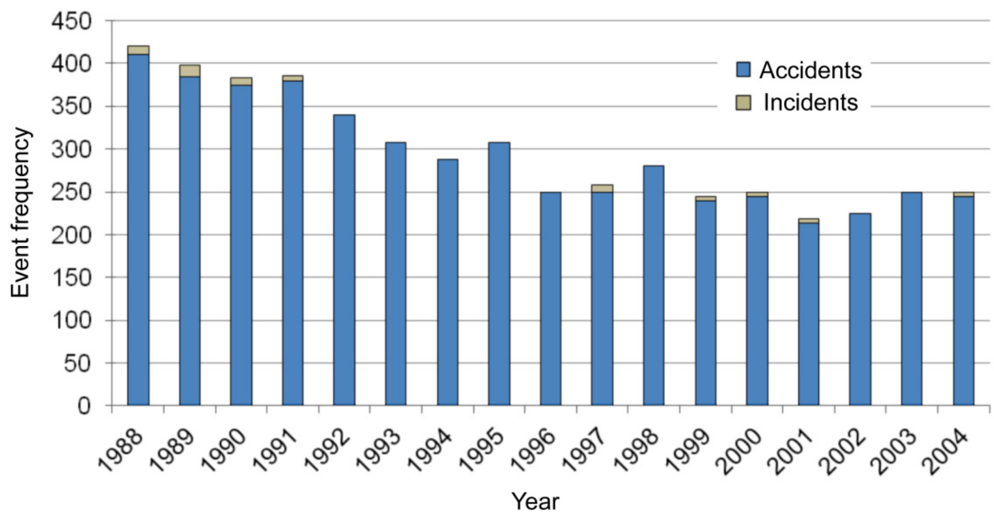

Figure 4.—Frequency of Part 91 loss of control events per year.

Table 2 shows the delineation of in-flight LOC accidents according to the phase of flight in which control was lost. In Part 121, the largest percentage of LOC events occurred during approach and landing, but takeoff LOC was the deadliest. In Part 135, LOC was least likely to occur en route, although among Nonscheduled Part 135, when control was lost en route, it almost always resulted in fatalities. In Part 91, en-route LOC was both the most frequent and the most often fatal.

TABLE 2.—FREQUENCY OF LOSS OF CONTROL ACCIDENTS BY PHASE OF FLIGHT AND BY OPERATION CATEGORY

Phase of flight	Operation category				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Total accidents	26	32	198	4961	5217
Takeoff	7	16	73	1542	1638
Fatal takeoff	7 (100%)	7 (443.8%)	30 (41%)	526 (34%)	570 (35%)
En route	8	6	56	1784	1854
Fatal en route	5 (62%)	4 (67%)	52 (93%)	1459 (82%)	1520 (82%)
Approach/landing	11	10	69	1635	1725
Fatal approach/landing	9 (82%)	8 (80%)	46 (67%)	650 (40%)	713 (41%)

2.1 Types of Loss of Control Events

To facilitate the examination of causal factors in these LOC accidents, the accidents and incidents were divided into three groups, which are defined below.

1. **LOC secondary to system/component failure/malfunction (SCFM)**.—In each of these events, LOC occurred secondary to a failure/malfunction. In some of these events, it may have been possible for the flight crew to maintain control, but in others the LOC was unavoidable.
2. **LOC secondary to aircraft damage**.—In these events, LOC was secondary to some type of aircraft damage, and this group is further subdivided into the following causes of damage:
   - Fire and/or explosion
   - Mid-air collision with another aircraft, bird, or skydiver
   - Weather-induced damage (from turbulence, hail, or lightning)
   - Pilot induced (most often exceeding the designed stress limits of the aircraft)
3. **Control upset**.—These events are further subdivided according to coexisting situations.
   - **Pilot induced**.—Control was lost due to the actions or inaction of the pilot, without other preceding or concurrent events.
   - **Low-altitude operations**.—In these accidents, control was lost in conjunction with some type of low-level maneuvering (aerobatics, aerial application, banner towing, evasive maneuvers to avoid a collision, sightseeing, scud running, etc.).
   - **Severe weather**.—In these events, the LOC was secondary to an encounter with severe weather—icing, turbulence, thunderstorm, or wind shear—or to inadequate ice/frost/snow removal prior to takeoff.
   - **Other events**.—The other events include loss of engine power, pilot incapacitation, or inadequate preflight inspections that resulted in open doors, gust locks that were not removed, or compromised Pitot systems.

Table 3 shows 31 percent of these accidents were precipitated by an SCFM, 23 percent by damage to the aircraft, while 46 percent followed an event that caused control upset. The one en-route LOC accident that is considered to be secondary to pilot-induced damage is the Belle Harbor, New York, crash in which the pilot inappropriately manipulated the rudder controls, leading to an overload failure of the vertical stabilizer. The one approach/landing LOC accident secondary to other events involved an inadequate preflight (open baggage door) and the subsequent failure to make a successful precautionary landing after takeoff.

TABLE 3.—FREQUENCY OF PART 121 LOSS OF CONTROL (LOC) ACCIDENTS BY ADVERSE CONDITIONS AND BY PHASE OF FLIGHT

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	2 (29%)	1 (12%)	5 (46%)	8 (31%)
Damage, fire	1	2	2	5
Damage, pilot	0	1	0	1
Total damage	1	3 (38%)	2 (18%)	6 (23%)
Control upset, pilot	2	2	1	5
Control upset, severe weather	2	2	2	6
Control upset, other events	0	0	1	1
Total control upset	4 (57%)	4 (50%)	4 (36%)	12 (46%)
Total	7 (100%)	8 (100%)	11 (100%)	26 (100%)

Among Scheduled Part 135 accidents during 1988 to 2004, there were 16 events with LOC during takeoff climb, 6 events with en-route LOC, and 10 events with LOC during approach or landing. Table 4 shows that 9 percent of these accidents were precipitated by an SCFM, 1 percent was attributed to damage, and 88 percent followed encounters with a control upset. Severe weather was a cause in 38 percent of all the Scheduled Part 135 LOC accidents. The two cases of control upset due to other events during takeoff involved an unsecured door and wake turbulence. The LOC accident due to pilot-induced damage during approach/landing involved scraping the aircraft on the runway following a failure to extend the landing gear, with a stall during the improperly executed aborted landing.

TABLE 4.—FREQUENCY OF SCHEDULED PART 135 LOSS OF CONTROL (LOC) ACCIDENTS BY ADVERSE CONDITIONS AND BY PHASE OF FLIGHT

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	1 (6%)	1 (17%)	1 (10%)	3 (9%)
Total damage, pilot	0 (0%)	0 (0%)	1 (10%)	1 (3%)
Control upset, pilot	7	2	4	13
Control upset, low-altitude maneuver	0	1	0	6
Control upset, severe weather	6	2	4	12 (38%)
Control upset, other events	2	0	0	2
Total control upset	15 (94%)	5 (83%)	8 (80%)	28 (88%)
Total	16 (100%)	6 (100%)	10 (100%)	32 (100%)

Among Nonscheduled Part 135 accidents during 1988 to 2004, there were 73 events with LOC on takeoff climb, 56 events with en-route LOC, and 69 events with LOC during approach or landing. As shown in Table 5, 12 percent of these accidents were precipitated by an SCFM. Of the en-route LOC events, 23 percent followed some sort of aircraft damage, and 25 percent occurred while operating at low altitude. Approximately 22 percent of the LOC events followed encounters with severe weather. One of the takeoff LOC due to other events involved an open door, and the other two had a loss of engine power. Of the two en-route LOC due to other events, one followed pilot incapacitation, and the other had a loss of engine power. One of the landing LOC due to other events involved an inadequate preflight (engine cowl plugs not removed), another followed pilot incapacitation, and eight had loss of engine power.

TABLE 5.—FREQUENCY OF NONSCHEDULED PART 135 LOSS OF CONTROL (LOC) ACCIDENTS BY ADVERSE CONDITIONS AND BY PHASE OF FLIGHT

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	11 (15%)	5 (9%)	8 (12%)	24 (12%)
Damage, fire	0	2	1	3
Damage, collision	0	6	0	6
Damage, weather	0	4	0	4
Damage, pilot	1	1	0	3
Total damage	1 (1%)	13 (23%)	1 (1%)	15 (8%)
Control upset, pilot	45 (62%)	12 (21%)	29 (42%)	86 (43%)
Control upset, low-altitude maneuver	0	14 (25%)	0	14
Control upset, severe weather	13	10	21 (31%)	44 (22%)
Control upset, other events	3	2	10	15
Total control upset	61(81%)	38 (67%)	60 (87%)	159 (80%)
Total	73 (100%)	56 (100%)	69 (100%)	198 (100%)

Among Part 91 accidents during 1988 to 2004, there were 1542 events with LOC on takeoff climb, 1784 events with en-route LOC, and 1635 events with LOC during approach or landing. As shown in Table 6, 8 percent of these accidents were precipitated by an SCFM, and 6 percent of them were secondary to aircraft damage. More than half were attributed to pilot error, while 7 percent followed an encounter with severe weather. Thirty-five percent of the en-route LOC accidents occurred while operating at low altitude. Thirty-three accidents had LOC secondary to pilot-induced damage. The two during takeoff followed a propeller strike shortly after liftoff and the nine during approach/landing followed failures to extend the landing gear. In the 22 en-route accidents, the pilot operated the aircraft in a manner that exceeded the designed stress limits. Thirty-nine of the 177 takeoff LOC accidents occurred due to other events involved an inadequate preflight (doors not secured, gust locks not removed, or Pitot tubes not cleared), 7 followed pilot incapacitation, 7 followed abrupt maneuvering, and 124 followed loss of engine power. Of the 106 en-route LOC accidents due to other events, 65 of these followed pilot incapacitation, 40 followed loss of engine power, and the final involved an inadequate preflight (open door). Of the 363 approach/landing LOC accidents due to other events, 316 followed loss of engine power, 19 followed pilot incapacitation, 14 involved inadequate preflight errors (relative to doors, fuel/oil caps, and Pitot systems), 9 involved evasive maneuvers, and the other 5 involved problems with banner towing equipment.

TABLE 6.—FREQUENCY OF PART 91 LOSS OF CONTROL (LOC) ACCIDENTS BY PHASE OF FLIGHT AND ADVERSE CONDITIONS

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	112 (7%)	114 (6%)	157 (10%)	383 (8%)
Damage, fire	2	17	12	31
Damage, collision	11	125	62	198
Damage, weather	0	29	0	29
Damage, pilot	2	22	9	33
Total damage	15 (1%)	193 (11%)	83 (5%)	292 (6%)
Control upset, pilot	1164 (76%)	572 (32%)	921 (56%)	2657 (53%)
Control upset, low-altitude maneuver	0	620	0	620
Control upset, severe weather	74	179	111	364
Control upset, other events	177	106	363	646
Total control upset	1415	1477	1395	4287
Total	1542 (100%)	1784 (100%)	1635 (100%)	4961 (100%)

Among Part 121 incidents during 1988 to 2004, there were 4 events with LOC during takeoff climb, 25 events with en-route LOC, and 9 with LOC during approach or landing. As shown in Table 7, about 79 percent of these events were precipitated by either a SCFM or damage to the aircraft, while 20 percent followed encounters with severe weather. The one approach/landing control upset incident that is considered to be due to other events involved wake turbulence.

TABLE 7.—FREQUENCY OF PART 121 LOSS OF CONTROL (LOC) INCIDENTS BY PHASE OF FLIGHT AND ADVERSE CONDITIONS

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	1	21 (84%)	6 (67%)	28 (58%)
Control upset, pilot	1	0	0	1
Control upset, severe weather	2	4	2	8 (20%)
Control upset, other events	0	0	1	1
Total control upset	3	4	3	10 (21%)
Total	4 (100%)	25 (100%)	9 (100%)	48 (100%)

Among Scheduled Part 135 incidents during 1988 to 2004, there was one event with LOC during takeoff climb, and four events with en-route LOC (see Table 8). The one control upset incident that is considered to be due to other events involved wake turbulence.

TABLE 8.—FREQUENCY OF SCHEDULED PART 135 LOSS OF CONTROL (LOC) INCIDENTS BY PHASE OF FLIGHT AND ADVERSE CONDITIONS

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	1 (100%)	2 (50%)	0	3 (60%)
Control upset, severe weather	0	1	0	1
Control upset, other events	0	1	0	1
Total control upset	0	2 (100%)	0	2 (40%)
Total	1 (100%)	4 (100%)	0	5 (100%)

Among Nonscheduled Part 135 incidents during 1988 to 2004, there were two events with LOC during takeoff climb, and six events with en-route LOC. As shown in Table 9, 75 percent of these events were precipitated by an SCFM.

TABLE 9.—FREQUENCY OF NONSCHEDULED PART 135 LOSS OF CONTROL (LOC) INCIDENTS BY PHASE OF FLIGHT AND ADVERSE CONDITIONS

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	1 (50%)	5 (83%)	0	6 (75%)
Control upset, pilot	1	0	0	1
Control upset, severe weather	0	1	0	1
Total control upset	1 (50%)	1 (17%)	0	2 (25%)
Total	2 (00%)	6 (100%)	0	8 (100%)

Among Part 91 incidents during 1988 to 2004, there were 18 events with LOC during takeoff climb, 35 events with en-route LOC, and 28 events with LOC during approach or landing, as shown in Table 10. One-third of these events were precipitated by an SCFM, while 15 percent followed encounters with severe weather. Four of the six incidents that are considered to be due to other events involved a loss of engine power; the other two had inadequate preflights (an inspection panel came loose and a door opened).

TABLE 10.—FREQUENCY OF PART 91 LOSS OF CONTROL (LOC) INCIDENTS BY PHASE OF FLIGHT AND ADVERSE CONDITIONS

Adverse condition leading to LOC	Phase of flight when LOC occurred			
	Takeoff	En route	Approach/landing	Takeoff, en route, and approach/landing combined
Total system/component failure/ malfunction	4 (22%)	19 (54%)	4 (14%)	27 (33%)
Control upset, pilot	11	5	20	36 (44%)
Control upset, severe weather	1	9	2	12 (15%)
Control upset, other events	2	2	2	6
Total control upset	14 (78%)	16 (46%)	24 (86%)	54 (67%)
Total	18 (100%)	35 (100%)	28 (100%)	81 (100%)

2.2 Causes of Loss of Control, Secondary to System/Component Failure/Malfunction (SCFM)

For LOC accidents in which SCFM was a cause, Tables 11 to 14 give more detailed information as to the specific system that suffered the SCFM. Table 11 provides this information for all phases of flight combined, while Tables 12 through 14 breaks out this information into the three phases of flight looked at in this study: takeoff, en route, and approach/landing.

As shown in Table 11, in Part 121, of the eight LOC accidents, 62 percent involved flight control systems. Of these Part 121 LOC accidents, aircraft control was not possible in five out of the eight accidents, improper procedures were used in one accident (landing gear malfunction), spatial disorientation occurred in another (navigation instrument malfunction), and the data record does not specify a cause for LOC in the other accident (a catastrophic and uncontained engine failure). In the NTSB data analysis, "flight controls" as a category of SCFM, refers to the entire flight control system, including ailerons, elevators, rudder, horizontal and vertical stabilizers, and the control stick or yoke. Most of these are failures of connections, cables, screws, and fatigue cracks. Failures of the autopilot and flight management computer are classified as being a part of the navigation system by the NTSB.

In Scheduled Part 135 flights, three LOC accidents followed SCFMs. Aircraft control was not possible in two of these accidents, and in the third, the pilot did not follow the proper emergency procedure following an engine failure.

TABLE 11.—SYSTEM/COMPONENT FAILURE/MALFUNCTION (SCFM) FREQUENCY IN LOSS OF CONTROL (LOC) ACCIDENTS BY SYSTEM AND OPERATION CATEGORY

SCFM system	Operation category				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Anti-ice/de-ice	0	0	0	2	2
Electrical	0	0	3	12	15
Engine	1	1 (33%)	11 (46%)	146 (38%)	159 (38%)
Flight control	5 (62%)	1 (33%)	2	78 (20%)	86 (21%)
Fuel system	0	0	3	39	42 (10%)
Heating	0	0	0	1	1
Inst/com/nav	1	0	0	23	24
Landing gear	1	0	0	6	7
Oxygen	0	0	0	2	2
Pitot heat	0	0	0	1	1
Pressurization	0	0	1	2	3
Propeller	0	1 (33%)	1	20	22
Structure	0	0	1	30	31
Vacuum pump	0	0	2	21	23
Total	8 (100%)	3 (100%)	24 (100%)	383 (100%)	418 (100%)

In Nonscheduled Part 135 flights, 24 LOC accidents followed SCFMs. Fourteen of these involved the engine or fuel system; in 12 of these, a loss of airspeed led to a stall, while for the other 2 accidents, the cause of the LOC was not specified. In six of the accidents, the NTSB ruled that the loss of aircraft control could not have been prevented, including one accident in which all persons onboard were incapacitated following decompression. In the remaining four accidents, the LOC was caused by spatial disorientation (two accidents, both vacuum pump failures), diverted attention because of the electrical failure during takeoff, and a stall (from ice buildup because the anti-ice system could not operate due to an electrical malfunction).

In Part 91 flights, 383 LOC accidents followed SCFM, 185 involved the engine or fuel system, and 78 involved flight control systems. The engine/fuel system and flight control systems accounted for 69 percent of Part 91 LOC accidents.

As shown in Table 12, of all LOC takeoff accidents following an SCFM, 40 percent followed an SCFM of the engine, while 33 percent followed an SCFM of flight control. In en-route LOC accidents, the most frequent SCFM systems were structures, flight control, and the engine, as shown in Table 13. During approach/landing LOC accidents, an engine SCFM preceded LOC in a majority of the accidents (Table 14).

TABLE 12.—SYSTEM/COMPONENT FAILURE/MALFUNCTION (SCFM) FREQUENCY IN LOSS OF CONTROL (LOC) ACCIDENTS DURING TAKEOFF BY SYSTEM AND OPERATION CATEGORY

SCFM system	Operation category				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Electrical	0	0	1	1	2
Engine	0	1 (100%)	6 (54%)	43 (38%)	50 (40%)
Flight control	2 (100%)	0	1	39 (35%)	42 (33%)
Fuel system	0	0	2	12	14
Inst/com/nav	0	0	0	1	1
Landing gear	0	0	0	3	3
Propeller	0	0	1	7	8
Structure	0	0	0	6	6
Total	2 (100%)	1 (100%)	11 (100%)	112 (100%)	126 (100%)

TABLE 13.—SYSTEM/COMPONENT FAILURE/MALFUNCTION (SCFM) FREQUENCY IN LOSS OF CONTROL (LOC) ACCIDENTS WHILE EN ROUTE BY SYSTEM AND OPERATION CATEGORY

SCFM system	Operation category				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Anti-ice/de-ice	0	0	0	1	1
Electrical	0	0	1	6	7
Engine	0	0	1	18 (16%)	19 (16%)
Flight control	1	1	0	19 (17%)	21 (17%)
Fuel system	0	0	0	6	6
Inst/com/nav	0	0	0	16 (14%)	16
Oxygen	0	0	0	2	2
Pitot heat	0	0	0	1	1
Pressurization	0	0	1	2	3
Propeller	0	0	0	2	2
Structure	0	0	1	21 (18%)	22 (18%)
Vacuum pump	0	0	1	20 (18%)	21
Total	1 (100%)	1 (100%)	5 (100%)	114 (100%)	121 (100%)

TABLE 14.—SYSTEM/COMPONENT FAILURE/MALFUNCTION (SCFM) FREQUENCY IN LOSS OF CONTROL (LOC) ACCIDENTS DURING APPROACH/LANDING BY SYSTEM AND SYSTEM AND OPERATION CATEGORY

SCFM system	Operation category				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Anti-ice/de-ice	0	0	0	1	1
Electrical	0	0	1	5	6
Engine	1	0	4	85 (54%)	90 (53%)
Flight control	2	0	1	20	23
Fuel system	0	0	1	21	22
Heating	0	0	0	1	1
Inst/com/nav	1	0	0	6	7
Landing gear	1	0	0	3	4
Propeller	0	1	0	11	12
Structure	0	0	0	3	3
Vacuum pump	0	0	1	1	2
Total	5 (100%)	1 (100%)	8 (100%)	157 (100%)	171 (100%)

In LOC accidents following an SCFM, the most common primary causes of the LOC were “inadequate airspeed and/or stall/spin” and “control was not possible” (Table 15). In 80 percent of the SCFM accidents the LOC due to inadequate airspeed and/or spin/stall was as a result of an engine or fuel SCFM.

TABLE 15.—FREQUENCY OF PRIMARY CAUSES OF PART 91 LOSS OF CONTROL (LOC) ACCIDENTS SECONDARY TO SYSTEM/COMPONENT FAILURE/MALFUNCTION BY SYSTEM

Primary cause of LOC	System			
	Engine or fuel	Flight control	Other systems	All systems combined
Control not possible	5	62 (80%)	40 (33%)	107 (28%)
Inadequate airspeed and/or stall/spin	149 (80%)	6	26 (22%)	181 (47%)
Spatial disorientation	0	0	26 (22%)	26
Pilot incapacitation	7	0	4	11
Diverted attention	5	1	5	11
Procedural or decision errors	8	0	4	12
Not specified	11	9	15	35
Total	185 (100%)	78 (100%)	120 (100%)	383 (100%)

2.3 Causes of Loss of Control, Secondary to Aircraft Damage

In Part 121, six LOC accidents followed aircraft damage. Aircraft control was not possible in four of these accidents (67 percent), and the data record does not specify a cause for LOC in the other two accidents that occurred outside the United States in the Dominican Republic and Ecuador.

In Scheduled Part 135, one LOC accident followed aircraft damage. As mentioned above, the pilot failed to extend the landing gear and scraped the aircraft along the runway, then stalled the aircraft during the improperly executed aborted landing.

In Nonscheduled Part 135, 15 LOC accidents followed aircraft damage. Airspeed was not maintained after an engine fire, resulting in a stall. In two other fires, the data record does not specify the cause for the LOC. Six of the accidents were mid-air collisions with other aircraft, after which aircraft control was not possible. Four in-flight breakups occurred after encounters with severe weather, leaving the aircraft uncontrollable. Another in-flight breakup was caused by the pilot flying with excessive airspeed, after which aircraft control was not possible. In the final accident, the pilot did not maintain proper alignment on the gravel bar he was using as a runway and damaged the stabilator by hitting a tree. The aircraft then stalled into the river. Of these accidents, LOC was caused because aircraft control not possible in 11 of the accidents, stall in 2, and unknown causes in the final 2 accidents.

In Part 91, 291 LOC accidents followed aircraft damage and the NTSB ruled that aircraft control was not possible in 251 of these (86 percent). Table 16 lists the causes of LOC in four groups defined by the cause of the damage.

TABLE 16.—FREQUENCY OF PRIMARY CAUSES OF PART 91 LOSS OF CONTROL (LOC) ACCIDENTS SECONDARY TO AIRCRAFT DAMAGE

Primary cause of LOC	Cause of aircraft damage				
	Fire	Collision	Weather	Pilot induced	All causes combined
Control not possible	18 (58%)	181 (91%)	29 (100%)	23 (70%)	251 (86%)
Inadequate airspeed and/or stall/spin	2	2	0	6	10
Spatial disorientation	1	0	0	0	1
Pilot incapacitation or impairment	2	7	0	0	9
Diverted attention	2	7	0		9
Not specified	6	1	0	4	11
Total	31 (100%)	198 (100%)	29 (100%)	33 (100%)	291 (100%)

2.4 Causes of Control Upset

Control upset is defined here as being caused by pilot error and/or LOC due to occurrences that cannot be regulated via aircraft technology. In Part 121, 12 accidents were classified as “control upset.” Three accidents followed in-flight encounters with icing, and two followed inadequate ice and/or frost removal before takeoff. Each of the following primary causes was responsible for one of the seven remaining accidents: inaccurate weight and/or balance (cargo loaded improperly), improper use of controls (flaps and slats not properly configured prior to takeoff), inadvertent control interference (deactivation of autopilot and movement of control column), an inadvertent stall from inadequate airspeed during level-off, a wind shear encounter during a missed approach, impairment of the flight crew due to fatigue, and an improperly secured cargo door.

In Scheduled Part 135, 28 accidents were classified as “control upset.” Six accidents were caused by inadequate ice and/or frost removal prior to takeoff. The primary causes of the other nine takeoff control upset accidents were three stalls from inadequate airspeed, one encounter with wake turbulence, one encounter with adverse winds (downdrafts), one premature liftoff from a wet runway, one improper decision to delay aborting the takeoff after the aircraft would not climb, one spatial disorientation during a low-visibility takeoff at night, and one inadequate preflight (improperly secured cargo door). Of the five en-route control upset accidents, one has no determined cause, one followed an encounter with icing, one followed an encounter with a thunderstorm, one was caused by spatial disorientation (flat lighting and snow-covered terrain), and the other was caused by an inadvertent stall from inadequate airspeed. There were eight control upset accidents during approach/landing. Two followed icing encounters, one followed an encounter with a thunderstorm, three were due to stalls, one was caused by the pilot’s failure to follow approved procedures for a single-engine approach, and one was caused by the improper use of controls (inadvertent activation of power levers).

The primary causes of the control upset accidents in Nonscheduled Part 135 and Part 91 are listed in Tables 17, 18, and 19. In some cases the data record does not include any causes or factors (mostly for accidents occurring outside the United States). In other cases the only cause listed is a “failure to maintain aircraft control.” This cause has no more meaning than “unknown,” but when the aircraft is not equipped with a cockpit recorder, when the pilot was not in communication with a tower at the time of the accident, and when there are no witnesses to the accident, a more detailed accident cause is understandably difficult to determine.

During takeoff, control upset in Nonscheduled Part 135 was most likely to be caused by adverse winds or inadequate ice/frost removal, and in Part 91, 40 percent of the control upset was caused by inadequate airspeed leading to a stall. En route, the most common cause of control upset in either category of operation was a stall. The next most common causes of control upset were icing (Part 135 Nonscheduled) and visual flight rules (VFR) into instrument meteorological conditions (IMC) (Part 91). During approach and landing, the most common cause of control upset in either category of operation was also a stall. The next most common causes were icing (Part 135 Nonscheduled) and adverse wind conditions (Part 91).

TABLE 17.—FREQUENCY OF PRIMARY CAUSES OF NONSCHEDULED PART 135 AND PART 91 LOSS OF CONTROL (LOC) ACCIDENTS DURING TAKEOFF FOLLOWING CONTROL UPSET

Primary cause of LOC	Operation	
	Nonscheduled Part 135	Part 91
Inadequate airspeed and/or stall	5	575 (40.6%)
Inadequate ice/frost removal	13 (21.3%)	33
Weather (WX), icing	0	4
WX, thunderstorm	0	4
WX, wind shear	0	21
WX, adverse winds	18 (30%)	200 (14%)
WX, obscuration	0	13
Visual flight rules into instrument meteorological conditions	0	31

TABLE 17.—Concluded.

Primary cause of LOC	Operation	
	Nonscheduled Part 135	Part 91
Spatial disorientation	1	37
Diverted attention	1	11
Wake turbulence	0	7
Inadequate preflight	2	48
Incorrect weight/balance	8	64
Incorrect or unsuitable runway	4	17
All available runway not used	0	3
Improper/premature liftoff	0	105
Improper handling	0	5
Improper use of controls	2	51
Procedural or decision error	0	30
Pilot incapacitation	0	7
Pilot impairment	0	16
Control interference	0	8
Passenger interference	0	7
Aircraft performance capability exceeded	0	28
Lack of experience	0	16
Aircraft control not maintained	5	58
Unknown	2	16
Total	61 (100%)	1415 (100%)

TABLE 18.—FREQUENCY OF PRIMARY CAUSES OF NONSCHEDULED PART 135 AND PART 91 LOSS OF CONTROL (LOC) ACCIDENTS EN ROUTE FOLLOWING CONTROL UPSET

Primary cause of LOC	Operation	
	Nonscheduled Part 135	Part 91
Inadequate airspeed and/or stall	10 (26%)	530 (36%)
Weather (WX), icing	5 (13%)	63
WX, thunderstorm	3	68
WX, turbulence	2	29
WX, wind shear	0	8
WX, adverse winds	0	33
WX, obscuration	0	50
WX, blizzard	1	0
Visual flight rules into instrument meteorological conditions	2	211 (14%)
Spatial disorientation	3	95
Diverted attention	0	6
Wake turbulence	1	3
Inadequate preflight	0	3
Incorrect weight/balance	0	7
Improper use of controls	0	12
Low-altitude maneuvering	3	83
Pilot incapacitation	0	63
Pilot impairment	1	55
Procedural/decision error	0	5
Control interference	0	9
Passenger interference	1	11
Aircraft performance capability exceeded	0	2
Lack of experience	0	14
Aircraft control not maintained	1	72
Unknown	5	45
Total	38 (100%)	1477 (100%)

TABLE 19.—FREQUENCY OF PRIMARY CAUSES OF NONSCHEDULED PART 135 AND PART 91 LOSS OF CONTROL (LOC) ACCIDENTS DURING APPROACH OR LANDING FOLLOWING CONTROL UPSET

Primary cause of LOC	Operation	
	Nonscheduled Part 135	Part 91
Inadequate airspeed and/or stall	21 (35%)	675 (48.4%)
Weather (WX), icing	11 (18%)	38
WX, thunderstorm	3	4
WX, wind shear	4	29
WX, turbulence	0	2
WX, adverse winds	3	267 (19%)
WX, obscuration	6	20
Visual flight rules into instrument meteorological conditions	0	18
Spatial disorientation	1	52
Diverted attention	0	8
Wake turbulence	1	27
Inadequate preflight	0	13
Incorrect weight/balance	3	2
Improper use of controls	2	54
Improper handling	0	4
Incorrect or unsuitable runway	0	1
Procedural/decision error	0	33
Pilot incapacitation	0	18
Pilot impairment	1	12
Control interference	1	0
Passenger interference	0	2
Aircraft performance capability exceeded	0	1
Lack of experience	0	19
Aircraft control not maintained	2	85
Unknown	1	11
Total	60 (100%)	1395 (100%)

The incident data, unfortunately, seldom includes enough details to determine a cause for the LOC incidents. Thus no attempt is made to summarize causal factor data for the incidents.

The accident data record often includes four or more causes, factors, or findings. In addition to the primary cause detailed above, Tables 20 to 22 list all of the recorded causes, factors, and findings relative to control upset for these accidents for takeoff, en route, and approach or landing phases of flight. Percentages are based on the total number of accidents in each operation category, not on the total number of causes, factors, or findings. For example, 51 percent of the Part 91 accidents with control upset during takeoff (1415 total accidents) list an inadvertent stall, spin, or mush as a cause/factor/finding in the data record.

TABLE 20.—FREQUENCY OF ALL CAUSES/FACTORS/FINDINGS OF LOSS OF CONTROL UPSET ACCIDENTS DURING TAKEOFF FOLLOWING CONTROL UPSET BY OPERATION CATEGORY

Causes/factors/findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Total number of accidents	4	15	61	1415	1495
Inadvertent stall/spin/mush	2 (50%)	5 (33%)	13 (21%)	722 (51%)	742 (50%)
Inadequate airspeed	1 (25%)	3 (20%)	15 (25%)	548 (39%)	567 (38%)
Weather (WX), winds	0	1	19 (31%)	344 (24%)	364 (24%)
Aircraft control not maintained	0	2	12 (20%)	302 (21%)	316 (21%)
Inadequate preflight	2 (50%)	3 (20%)	17 (28%)	211	233 (16%)
Inadequate experience	0	0	3	162	165
Improper (premature) liftoff	0	1	0	158	159
High-density altitude	0	0	1	158	159
Improper or inadequate compensation for wind conditions	0	1	8	132	141
Improper use of controls	2 (50%)	1	3	131	137
Incorrect weight/balance	1 (25%)	3	9	119	132
Improper climb	0	1	2	88	91

TABLE 20.—Continued.

Causes/factors/findings	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
WX, obscuration	0	1	4	73	78
Wrong or unsuitable runway	0	0	4	74	78
Light (night)	0	1	6	67	74
Abort delayed or not performed	0	1	2	69	72
Improper planning/decision	0	1	7	58	66
Abrupt, evasive, or improperly executed maneuver	0	0	1	62	63
Spatial disorientation	0	0	1	58	59
Inadequate WX evaluation	0	0	6	52	58
Incapacitation or impairment	0	1	0	53	54
Inadequate ice/frost removal	2 (50%)	6 (40%)	9	36	53
Diverted attention	0	0	3	46	49
Aircraft performance capability exceeded	0	0	2	47	49
Procedures and/or directives not followed	2 (50%)	2	4	65	73
Improper or inadequate supervision by certified flight instructor or pilot not flying	0	0	0	38	38
WX, icing	2 (50%)	2	8	25	37
Improper aircraft handling	0	0	0	35	35
Improper or inadequate remedial action	0	0	1	33	34
Climb not possible	0	0	4	27	31
Complacency, overconfidence, or ostentatious display	1 (25%)	0	0	30	31
Visual flight rules into instrument meteorological conditions	0	0	0	31	31
Runway condition	0	2	3	26	31
WX, turbulence	0	0	1	29	30
Checklist not followed	0	0	1	28	29
WX, snow or rain	1	2	4	19	26
Aircraft control not possible	1 (25.0%)	2	0	20	23
Flight into adverse WX	0	0	1	22	23
WX, wind shear	0	0	0	23	23
Improper alignment	0	0	1	19	20
Lack of certification or qualification	0	0	0	20	20
No causes/factors/findings	0	0	3	16	19
Company and/or operator deficiency	3 (75%)	3 (20%)	7	6	19
Operation with known aircraft deficiency	0	0	0	19	19
Anxiety/depression/panic/pressure	0	1	1	16	18
Improper altitude	0	1	0	16	17
All available runway not used	0	0	0	15	15
Improper or inadequate training	1 (25%)	0	1	13	15
FAA deficiency	4 (100%)	2	1	7	14
WX, thunderstorm or microburst	0	0	1	11	12
Banner or glider tow flight	0	0	0	10	10
Control interference	0	0	0	10	10
Poor judgment	0	0	0	8	8
Manufacturing deficiency	1 (25%)	1	0	6	8
Fatigue	0	0	0	7	7
Cargo shifted	0	0	2	5	7
Wake turbulence	0	1	0	6	7
Passenger interference	0	0	0	7	7
Gust lock not removed	0	0	0	5	5
Light (dusk or dawn)	0	0	0	5	5
WX, high temperatures	0	0	0	4	4

TABLE 20.—Concluded.

Causes/factors/findings	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 91, 135, and 121 combined
Improper or inadequate air traffic control service	0	0	0	3	3
Improper or inadequate communication with air traffic control	0	0	0	2	2
Light (sun glare)	0	0	0	2	2
Visual/aural perception	0	0	0	2	2
Light (flat)	0	0	1	0	1
Inadequate crew coordination	1 (25%)	0	0	0	1

TABLE 21.—FREQUENCY OF ALL CAUSES/FACTORS/FINDINGS OF LOSS OF CONTROL (LOC) ACCIDENTS EN ROUTE FOLLOWING CONTROL UPSET BY OPERATION CATEGORY

Causes/factors/findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
Total number of accidents	4	5	38	1477	1524
Inadvertent stall/spin/mush	2 (50%)	2 (40%)	12 (32%)	644 (44%)	660 (43%)
Aircraft control not maintained	1 (25%)	2 (40%)	12 (32%)	478 (32%)	493 (32%)
Inadequate airspeed	2 (50%)	2 (40%)	13 (34.2%)	451 (30.5%)	468 (31%)
Weather (WX), obscuration	0	0	9 (24%)	360 (24%)	369 (24%)
Abrupt, evasive, or improperly executed maneuver	0	0	7	295 (20%)	302 (20%)
Spatial disorientation	0	1 (20%)	4	269	274
Inadequate experience	0	0	4	246	250
Visual flight rules into instrument meteorological conditions	0	1 (20%)	3	223	227
Light (night)	0	0	8 (21%)	183	191
Flight into adverse weather	0	0	4	181	185
Improper planning/decision	0	1 (20%)	6	168	175
Incapacitation or impairment	0	0	5	163	168
WX, snow or rain	0	2 (40%)	4	131	137
Inadequate WX evaluation	0	0	5	125	130
WX, icing	2 (50%)	2 (40%)	7	96	107
WX, turbulence	0	1 (20%)	2	106	109
WX, winds	0	0	3	102	105
WX, thunderstorm/microburst	0	1 (20%)	4	83	88
Inadequate preflight	0	0	1	73	74
Improper or inadequate remedial action	1 (25%)	0	1	68	70
Complacency or overconfidence	0	0	0	64	64
Improper or inadequate aircraft handling	0	0	1	58	59
High-density altitude	0	0	1	53	54
No causes/factors/findings		1 (20%)	4	44	49
Procedures/directives not followed	0	0	2	47	49
Improper use of controls	2 (50%)	1 (20%)		44	47
Incorrect weight/balance	0	0	0	44	44
Improper or inadequate supervision by certified flight instructor or pilot not flying	0	0	0	40	40
Improper altitude	0	0	1	36	37
Diverted attention	0	1 (20%)		35	36
Anger/anxiety/depression/panic/ pressure	0	0	2	34	36
Poor judgment	0	0	0	31	31
Lack of certification or qualification	0	0	0	29	29
Ostentatious display	0	0	0	28	28

TABLE 21.—Concluded.

Causes/factors/findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
Aircraft control not possible	0	0	0	26	26
Improper or inadequate training	0	0	2	21	23
Fatigue	0	1 (20%)	1	19	21
Improper or inadequate compensation for wind conditions	0	0	0	18	18
Banner or glider tow flight	0	0	0	18	18
Lost and/or disoriented	0	0	0	18	18
WX, wind shear	0	0	0	15	15
Light (dusk or dawn)	0	0	0	13	13
Operation with known aircraft deficiency	0	0	0	12	12
Control interference	1 (25%)	0		11	12
Passenger interference	0	0	1	10	11
FAA deficiency	1 (25%)	0	3	6	10
Company/operator deficiency	0	0	2	7	9
Visual/aural perception	0	0	0	8	8
Aircraft performance capability exceeded	0	0	0	8	8
Pitot blockage	0	0	0	6	6
Improper or inadequate air traffic control service	0	0	0	6	6
WX information inaccurate or unavailable	0	0	0	5	5
Manufacturing deficiency	1 (25%)	0	1	3	5
Inadequate crew coordination	1 (25%)	1 (20%)	0	2	4
Wake turbulence	0	0	1	3	4
Climb not possible	0	0	0	3	3
Improper alignment	0	0	0	2	2
Improper climb	0	0	0	2	2
Improper descent	0	0	0	1	1
Light (flat)	0	1 (20%)	0	0	1
Light (Sun glare)	0	0	0	1	1

TABLE 22.—FREQUENCY OF ALL CAUSES/FACTORS/FINDINGS OF LOSS OF CONTROL (LOC) ACCIDENTS ON APPROACH/LANDING FOLLOWING CONTROL UPSET BY OPERATION CATEGORY

Causes/factors/findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
All accidents	4	8	60	1395	1467
Inadvertent stall/spin/mush	1 (25.0%)	5 (62.5%)	30 (50.0%)	716 (51.3%)	752 (51%)
Inadequate airspeed	0	4 (50.0%)	23 (38%)	604 (43%)	631 (43%)
Weather (WX), winds	0	0	9 (15%)	373 (27%)	382 (26%)
Aircraft control not maintained	0	0	12 (20%)	363 (26%)	375 (26%)
Inadequate experience	0	1	5	174	180
Improper or inadequate compensation for wind conditions	0	0	3	174	177
Improper planning/decision	3 (75%)	4 (50%)	14 (23%)	128	149
Improper use of controls	1 (25%)	1	4	137	143
WX, obscuration	0	2 (25%)	15 (25%)	106	123
Procedures/directives not followed	1 (25%)	2 (25%)	7	96	106
Light (night)	0	1	7	86	94
Abort delayed or not performed	0	1	4	89	94
Abrupt, evasive, or improperly executed maneuver	0	0	2	85	87
Spatial disorientation	0	0	2	68	70
WX, icing	1 (25%)	3 (38%)	15 (25%)	45	64

Table 22.—Concluded.

Causes/factors/findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
Improper or inadequate supervision by certified flight instructor or pilot not flying	0	0	0	68	68
Improper or inadequate remedial action	1 (25%)	0	5	56	62
Incapacitation or impairment	0	0	1	61	62
Inadequate preflight	1 (25%)	0	2	57	60
Improper alignment	0	0	1	52	53
Flight into adverse weather	0	1	9	42	52
Inadequate weather evaluation	1 (25%)	0	4	47	52
WX, turbulence	0	0	4	44	48
WX, snow or rain	0	0	6	34	40
Improper or inadequate aircraft handling	2 (50%)	1	1	35	39
Diverted attention	0	0	1	33	34
Improper altitude	0	0	2	32	34
High-density altitude	0	0	1	32	33
WX, wind shear	1 (25%)	0	5	30	36
Wake turbulence	0	0	1	27	28
Visual flight rules into instrument meteorological conditions	0	0	1	23	24
Improper glidepath	0	0	1	21	22
Complacency or overconfidence	0	0	0	20	20
Wrong or unsuitable runway	0	0	0	18	18
Improper climb	0	0	1	16	17
Aircraft control not possible	0	0	3	16	19
WX, thunderstorm or microburst	1 (25%)	1	4	13	19
Incorrect weight/balance			2	15	17
Company/operator deficiency	2 (50%)	3 (38%)	8	4	17
Operation with known aircraft deficiency			1	15	16
Improper or inadequate training	1 (25%)	2 (25%)	2	11	16
Improper or inadequate air traffic control service	1 (25%)	1		12	15
Lost or disoriented	0	0	0	14	14
No causes/factors/findings	0	0	1	11	12
FAA deficiency	2 (50%)	2 (25%)	0	7	11
Poor judgment	1 (25%)	0	2	7	10
Control interference	0	0	0	10	10
Anxiety/depression/panic/pressure	0	0	0	9	9
Fatigue	1 (25%)	0	2	5	8
Aircraft performance capability exceeded	0	0	1	7	8
Improper descent	0	0	0	6	6
Lack of certification or qualification	0	0	0	5	5
Banner tow flight	0	0	0	5	5
Visual impairment (not physical)	0	0	0	5	5
Manufacturing deficiency	2 (50%)	0	0	2	4
Climb not possible	0	0	0	4	4
Passenger interference	0	0	0	4	4
Light (dusk or dawn)	0	0	1	3	4
Weather information inaccurate or unavailable	0	0	0	3	3
Light (Sun glare)	0	0	0	3	3
Visual/aural perception	0	0	0	3	3
Pitot blockage	0	0	0	2	2
Improper or inadequate communication with air traffic control	0	0	1	1	2
Cargo shifted	0	0	1	0	1
WX, high temperatures	0	0	0	1	1
Light (flat)	0	0	0	1	1

Table 23 provides all of the recorded causes, factors and findings for all control upset accidents by operation category, while Table 24 provides only the primary causes for all the control upset accidents by operation category.

TABLE 23.—FREQUENCY OF ALL CAUSES/FACTORS/FINDINGS OF ALL LOSS OF CONTROL (LOC) ACCIDENTS FOLLOWING CONTROL UPSET BY OPERATION CATEGORY

Causes/factors/findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
All accidents	13	27	159	4287	4486
Inadvertent stall/spin/mush	5 (38%)	12 (44%)	55 (35%)	2082 (49%)	2154 (48%)
Inadequate airspeed	3 (23%)	9 (33%)	51 (32%)	1603 (37%)	1666 (37%)
Aircraft control not maintained	1	4	36	1143 (27%)	1184 (26%)
Weather (WX), winds	0	1	31	819	851
Abrupt, evasive, or improperly executed maneuver	0	0	12	582	595
WX, obscuration	0	1	13	433	477
Spatial disorientation	0	1	7	395	403
Improper planning/decision	3 (23%)	6	27	354	390
Inadequate preflight	3 (23%)	3	20	341	367
Light (night)	0	2	21	336	359
Improper or inadequate compensation for wind conditions	0	1	11	324	336
Improper use of controls	5 (38%)	3	7	312	327
Incapacitation or impairment	0	1	6	277	284
Visual flight rules into instrument meteorological conditions	0	1	4	277	282
Flight into adverse weather	0	1	14	245	260
Inadequate weather evaluation	1	0	15	224	240
Procedures/directives not followed	3	4	13	208	228
WX, icing	5	7	30	166	208
WX, snow or rain	1	4	14	184	203
Incorrect weight/balance	1	3	11	176	191
WX, turbulence	0	1	7	179	187
Abort delayed or not performed	0	2	6	158	166
Improper or inadequate remedial action	2	0	7	157	166
High-density altitude	0	0	3	243	246
Improper (premature) liftoff	0	1	0	158	159
Improper or inadequate supervision by certified flight instructor or pilot not flying	0	0	0	146	146
Complacency, overconfidence, or ostentatious display	1	0	0	142	143
Diverted attention	0	1	4	114	119
WX, thunderstorm or microburst	1	2	9	107	119
Improper climb	0	1	3	106	110
Improper or inadequate aircraft handling	2	1	2	93	98
Wrong or unsuitable runway	0	0	4	92	96
Improper altitude	0	1	3	84	88
No causes, factors, or findings	0	1	8	71	80
Improper alignment	0	0	2	73	75
WX, wind shear	1	0	5	68	74
Aircraft control not possible	1	2	3	62	68
Anxiety/depression/panic/pressure	0	1	3	59	63
Aircraft performance capability exceeded	0	0	2	55	57
Lack of certification or qualification	0	0	0	54	54
Improper or inadequate training	2	2	5	45	53
Inadequate ice/frost removal	2	6	9	36	53
Poor judgment	1	0	2	46	49

TABLE 23.—Concluded.

Causes or factors or findings	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
Operation with known aircraft deficiency	0	0	1	46	47
Company/operator deficiency	5 (38%)	6	17	17	45
Wake turbulence	0	1	2	36	39
Fatigue	1	1	3	34	39
Climb not possible	0	0	4	34	38
FAA deficiency	7 (54%)	4	4	20	35
Improper aircraft handling	0	0	0	35	35
Banner or glider tow flight	0	0	0	33	33
Control interference	1	0	0	31	32
Lost or disoriented	0	0	0	32	32
Runway condition	0	2	3	26	31
Checklist not followed	0	0	1	28	29
Manufacturing deficiency	4 (31%)	1	7	13	25
Improper or inadequate air traffic control service	1	1	0	21	23
Improper glidepath	0	0	1	21	22
Passenger interference	0	0	1	21	22
Light (dusk or dawn)	0	0	1	21	22
All available runway not used	0	0	0	15	15
Visual/aural perception	0	0	0	13	13
Pitot blockage	0	0	0	8	8
WX information inaccurate or unavailable	0	0	0	8	8
Cargo shifted	0	0	3	5	8
Improper descent	0	0	0	7	7
Light (Sun glare)	0	0	0	6	6
Gust lock not removed	0	0	0	5	5
Inadequate crew coordination	2	1	0	2	5
Visual impairment (not physical)	0	0	0	5	5
WX, high temperatures	0	0	0	5	5
Improper or inadequate communication with air traffic control	0	0	1	3	4
Light (flat)	0	1	1	1	3

TABLE 24.—FREQUENCY OF PRIMARY CAUSES FOR ALL LOSS OF CONTROL (LOC) ACCIDENTS BY OPERATION CATEGORY

Primary cause of LOC	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
Total primary causes	26 (100%)	32 (100%)	198 (100%)	4961 (100%)	5217 (100%)
Inadequate airspeed and/or stall	1	8 (25%)	51 (26%)	1971 (40%)	2031 (39%)
Weather (WX), adverse winds	0	1	21	500	522
Aircraft control not possible	9 (35%)	2	17	358	386
Visual flight rules into instrument meteorological conditions	0	0	2	260	262
Aircraft control not maintained	0	0	8	215	223
Spatial disorientation	1	2	7	211	221
Unknown	0	1	12	118	134
WX, icing	3	3	16	105	127
Improper use of controls	0	1	4	117	123
Pilot incapacitation	0	0	0	108	108
Improper/premature liftoff	0	1	0	105	106
WX, obscuration	0	0	6	83	89
Low-altitude maneuvering	0	0	3	83	86

TABLE 24.—Concluded.

Primary cause of LOC	Operation				
	Part 121	Scheduled Part 135	Nonscheduled Part 135	Part 91	Part 121, 135, and 91 combined
Pilot impairment	1	0	2	83	86
Incorrect weight/balance	1	0	11	73	85
WX, thunderstorm	0	2	6	76	84
Procedural or decision error	1	3	0	80	84
Inadequate preflight	1	1	2	64	68
WX, wind shear	1	0	4	58	63
Inadequate ice/frost removal	2	6	13	33	54
Lack of experience	0	0	0	49	49
Diverted attention	0	0	2	45	47
Wake turbulence	0	1	2	37	40
WX, turbulence	0	0	2	31	33
Aircraft performance capability exceeded	0	0	0	31	31
Incorrect or unsuitable runway	0	0	4	18	22
Passenger interference	0	0	1	20	21
Control interference	1	0	1	17	19
Improper handling	0	0	0	9	9
All available runway not used	0	0	0	3	3
WX, blizzard	0	0	1	0	1

Overall, the most common cause/factor/finding of all upset-related accidents was inadvertent stall/spin/mush.

Because of a combination of the small number of control upset accidents in Part 121 and the large number of causal factors implicated in each of these accidents, it is difficult to determine a few “most likely” causes in Part 121. However, accidents in Part 121 operations are more likely than those in other flight categories to have some blame placed on improper use of controls, icing, company/operator deficiency, manufacturing defects, and FAA deficiencies. In the NTSB accident data, “improper use of controls” involves a pilot error with the use of controls and not a failure of the control system. Examples are incorrect trim or flap setting for a flight attitude, or not using anti-ice/de-ice equipment, or not lowering landing gear.

In Scheduled Part 135 accidents, the most likely cause, factor, or finding during takeoff was inadequate ice/frost removal. During the en-route phase of flight, the most likely causes of control upset were stall/spin/mush, inadequate airspeed, icing, and improper use of controls. During the approach/landing phases of flight, the most likely causes of control upset were stall/spin/mush.

In Nonscheduled Part 135 accidents, the most likely cause, factor, or finding during takeoff was winds. During the en-route and approach/landing phases of flight, the most likely cause, factor, or finding of control upset was inadequate airspeed.

In Part 91 accidents, the most likely cause, factor, or finding during takeoff was inadequate ice/frost removal. During the en-route phase of flight, the most likely causes of control upset were stall/spin/mush, inadequate airspeed, icing, and improper use of controls. During the approach/landing phases of flight, the most likely cause, factor, or finding of control upset was stall/spin/mush.

In Part 91 accidents, the most likely cause, factor, or finding during all phases of flight was inadvertent stall/spin/mush.

In looking at only the primary cause of the control upset accidents, in Part 121, aircraft control was not possible in more than one-third of all LOC accidents. In the other three flight categories combined, more than 39 percent of the LOC was primarily caused by inadequate airspeed and/or stall.

2.5 Accident and Incident Data Analyses Conclusions

In-flight LOC is a serious aviation problem. Well over half of the LOC accidents included at least one fatality (80 percent in Part 121), and roughly half of all aviation fatalities in the studied time period occurred in conjunction with LOC. Due to the level of aircraft damage and injury that is likely to occur, LOC events are rarely considered incidents

In Part 121, LOC was somewhat more likely to occur during approach and landing (as opposed to takeoff or en route), but during takeoff, a LOC was most likely to result in a fatality. In Part 135 flights, LOC was most likely to occur during takeoff, although when control was lost during approach/landing 80 percent of the accidents resulted in fatalities. En-route LOC was both the most frequent and the most often fatal of the three phases in Part 91 flights.

In 31 percent of Part 121 LOC accidents, the LOC was secondary to an SCFM, compared with 8 to 12 percent of the accidents in other flight operation categories. Twenty-three percent of the Part 121 LOC accidents were secondary to aircraft damage (most often due to fire), compared with 3 to 8 percent of the accidents in other flight operation categories. As a result, for roughly 35 percent of the LOC accidents in Part 121, aircraft control was not possible, compared with 6 to 9 percent of the accidents in other flight operation categories. In flights other than Part 121, 25 to 40 percent of the LOC was caused by inadequate airspeed leading to an inadvertent stall. Icing (both preflight and in-flight) and adverse winds were the primary cause of a large number of accidents. Other frequently cited causes for LOC are inadequate preflight, improper planning or decisions, and flying in obscuration or at night.

3.0 NASA Analyses of Aviation Safety Reporting System (ASRS) Incident Data

3.1 Introduction

This section examines the composition of LOC incidents as reported in the ASRS. ASRS is a voluntary, nonpunitive, self-reporting system administered by NASA Ames Research Center that includes incident reports submitted by members of the flight crew and other persons working in the aviation industry. The ASRS reports do not represent an unbiased sample of aviation incidents, and the results presented here should not be considered statistically representative, but rather informational in nature. The Integrated Resilient Aircraft Control (IRAC) Project is focused on technologies that allow aircraft to operate in adverse conditions including loss of aircraft control and weather-related events. A previous IRAC report dealt with the topic of aircraft icing (Ref. 6), while this report will focus on LOC.

Data used in this analysis are from the years January 1993 to March 2008. While the ASRS online database includes incidents starting in 1988, information on the Federal Aviation Regulation (FAR) part is available only beginning in 1993. Since other flight operations, such as Part 91 (general aviation), may have substantially different data compared with Parts 121 and 135, it was decided to use only those years for which FAR part was known. During this time period, there were 61,479 incident reports for Part 121 operations, 6208 incident reports for Part 135 operations, and 27,977 incident reports for Part 91 operations. Each ASRS incident report lists the primary problem (or cause), an if applicable, the component involved. While this categorization is performed by the experts at ASRS, the IRAC systems analysis team further categorized those components into groups based on aircraft subsystems.

To obtain statistical information, the ASRS Web tool was used to query the database. Our initial selection criterion was incidents in which the “anomaly” was “loss of control.” The Web tool allows the user to export the results to a Microsoft Excel (Microsoft Corporation) file, and relevant information such as “FAR part” and “Primary Problem” were kept. Since the Web tool’s data export function only includes those fields that can be queried using the tool, component information was later obtained through permission of the ASRS team at NASA Ames Research Center. These data were provided in a Microsoft Excel file with only the component and ASRS Incident Report Number (ACN), and were matched to the exported data using the ACN. After combining the data in one file, the aircraft system categorization was added. Statistical analysis system (SAS) software was then used to perform the statistical analysis.

3.2 Primary Problems in Loss of Control Incidents

For the years January 1993 to March 2008, there were 1285 LOC incidents in the ASRS database for Part 121, 282 LOC incidents for Part 135, and 2075 LOC incidents for Part 91. Three primary problems (causes) account for 972 (76 percent) of the Part 121 incidents, 244 (87 percent) of the Part 135 incidents and 1900 (92 percent) of the Part 91 incidents: flight crew human performance, aircraft, and weather. These areas will be the focus in this report. The total primary problem breakdown can be seen in Table 25.

Because the IRAC Project is looking for technologies that can be incorporated in an aircraft, the specific areas of the aircraft that have been causing the most problems were more closely examined. Table 26 provides those LOC incidents that involved a component or system. For Part 121 incidents, an issue with air flight control was the most frequently cited (22 percent). Landing gear was cited most frequently in Part 135 operations (36 percent) and in Part 91 operations (24 percent.)

A closer look is provided at those components and systems that were involved in the three most frequent primary problems: human performance, aircraft, and weather.

The human performance category includes the flight crew, air traffic control, cabin crew, and/or passengers. Looking at Table 27, the largest causes of human performance incidents are related to the human's interaction with the landing gear, brakes, air flight control, and propulsion systems. These four systems account for over 68 percent of all LOC incidents related to human interaction with these systems. Later in the analysis, the top contributors to LOC incidents will be examined in more detail.

TABLE 25.—FREQUENCY OF PRIMARY PROBLEMS IN LOSS OF CONTROL INCIDENTS BY OPERATION CATEGORY

Primary problem	Operation category			
	Part 121	Part 135	Part 91	Part 91, 121, and 135 combined
Flight crew human performance	338 (26%)	106 (38%)	1217 (59%)	1661 (46%)
Aircraft	335 (26%)	96 (34%)	448 (22%)	879 (24%)
Weather	299 (23%)	42 (15%)	235 (11%)	576 (16%)
Airport	63	16	41	120
Environmental factor	71	8	33	112
Ambiguous	43	4	55	102
Air traffic control human performance	33	6	13	52
Maintenance human performance	27	3	17	47
Company	40	1	4	45
Other	18	0	6	24
Airspace structure	6	0	3	9
Federal Aviation Administration	7	0	0	7
Passenger human performance	1	0	3	4
Navigational facility	2	0	0	2
Cabin crew human performance	1	0	0	1
Chart or publication	1	0	0	1
Total	1285 (100%)	282 (100%)	2075	3642 (100%)

TABLE 26.—FREQUENCY OF COMPONENTS OR SYSTEMS INVOLVED IN LOSS OF CONTROL (LOC) INCIDENTS BY OPERATION CATEGORY

Component or system	Operation category			
	Part 121	Part 135	Part 91	Part 91, 121, and 135 combined
Landing gear	102 (19%)	47 (36%)	208 (26%)	357 (24%)
Brakes	56	18	166 (21%)	240 (16%)
Air flight control	117 (22%)	5	85	207
Propulsion system	61	17	104 (13%)	182
Control surfaces	73	15	56	144
Monitoring	33	4	33	70
Structures	6	5	14	41
Electrical	9	2	14	25
Miscellaneous	16	2	7	25
Hydraulics	18	1	5	24
Anti-icing	7	3	13	23
Communications	3	2	14	19
Navigation	8	0	10	18
Fuel system	0	0	17	17
Aircraft management	6	3	6	15
Furnishings and equipment	7	3	5	15
Weather systems	11	1	2	14
Helicopter	4	1	8	13
Environmental control	5	0	4	9
Collision avoidance systems	2	0	0	2
Navigation system	0	0	2	2
Oil systems	0	0	1	1
Total	544 (100%)	129 (100%)	790 (100%)	1463 (100%)

TABLE 27.—FREQUENCY OF COMPONENTS OR SYSTEMS INVOLVED IN LOSS OF CONTROL INCIDENTS WITH PRIMARY PROBLEM: HUMAN PERFORMANCE BY OPERATION CATEGORY

Component or system	Operation category			
	Part 121	Part 135	Part 91	Part 91, 121, and 135 combined
Landing gear	32 (19%)	10 (36%)	78 (26%)	120 (24%)
Brakes	28	6	58	92
Air flight control	39	2	47	88
Propulsion system	20	5	57	82
Control surfaces	12	5	32	49
Monitoring	14	2	9	25
Miscellaneous	9	0	6	15
Structures	0	1	12	13
Electrical	5	1	6	12
Fuel system	0	0	12	12
Navigation	5	0	6	11
Anti-icing	2	1	6	9
Communications	0	1	7	8
Helicopter	1	1	5	7
Furnishings and equipment	1	2	2	5
Hydraulics	3	0	2	5
Aircraft management	3	1	0	4
Weather systems	8	1	0	9
Environmental control	2	0	2	4
Navigation system	0	0	1	1
Total	178 (100%)	38 (100%)	349 (100%)	565 (100%)

For aircraft-related LOC incidents seen in Table 28, the landing gear problems are the largest source of incidents. Incidents related to brakes, air flight control, control surfaces, and propulsion systems follow. The important thing to note about this list is that these incidents are caused primarily by aircraft problems, not human-related factors. So while we could dismiss the fact that landing gear was near the top of the list for incidents attributed to human performance errors, the fact that it is on top of this list is notable.

TABLE 28.—FREQUENCY OF COMPONENTS OR SYSTEMS INVOLVED IN LOSS OF CONTROL INCIDENTS WITH PRIMARY PROBLEM: AIRCRAFT BY OPERATION CATEGORY

Component or system	Operation Category			
	Part 121	Part 135	Part 91	Part 91, 121, and 135 combined
Landing gear	52 (21%)	36 (50%)	107 (30%)	195 (29%)
Brakes	21	10	95 (27%)	126 (19%)
Air flight control	56	3	29	88
Control surfaces	50	8	17	75
Propulsion system	20	9	41	70
Monitoring	11	0	14	25
Structures	3	2	12	17
Hydraulics	12	1	3	16
Aircraft management	3	2	5	10
Electrical	3	1	6	10
Furnishings and equipment	3	1	3	7
Anti-icing	3	0	2	5
Communications	1	1	3	5
Helicopter	2	0	3	5
Miscellaneous	3	1	1	5
Environmental control	2	0	2	4
Fuel system	0	0	4	4
Navigation	2	0	2	4
Navigation system	0	0	1	1
Oil system	0	0	1	1
Weather systems	1	0	0	1
Total	248 (100%)	75 (100%)	351 (100%)	674 (100%)

In LOC accidents with the primary problem of weather, the components or systems that were involved were much more varied than in the previous primary problem categories of human performance and aircraft (Table 29). In Part 121, the most frequent components or systems found to contribute to LOC incidents were air flight control and propulsion systems. Overall, the top four systems (air flight control, propulsion systems, monitoring, and control surfaces) account for 52 percent of all the primary problem LOC incidents in the weather category.

After looking into the top three primary problems more in depth, the top five aircraft systems in terms of incidents caused have been looked at more closely. Landing gear, brakes, air flight control, propulsion system, and control surfaces together accounted for over 77 percent of the incidents that had components reported. In the following sections, we will highlight the individual components in each of these systems that account for the majority of LOC incidents caused.

3.3 Most Frequently Cited Aircraft Systems in Loss of Control Incidents

3.3.1 Landing Gear

Landing gear was the most frequently cited system in LOC incidents. A breakdown of incident frequencies for all landing gear components can be seen in Table 30. Nose-wheel steering accounted for 21 percent of these incidents. The top five most frequently cited landing gear components (nose-wheel steering, nose gear, main gear, antiskid system, gear extend/retract mechanism, and landing gear) account for over 75 percent of the landing gear incidents. (These five components are shaded in Table 30.)

TABLE 29.—FREQUENCY OF COMPONENTS OR SYSTEMS INVOLVED IN LOSS OF CONTROL INCIDENTS WITH PRIMARY PROBLEM: WEATHER BY OPERATION CATEGORY

Component or system	Operation Category			
	Part 121	Part 135	Part 91	Part 91, 121, and 135 combined
Air flight control	11 (20%)	0	6	17 (16%)
Propulsion system	10 (19%)	2 (22%)	2	14
Monitoring	4	1	8	13
Control surfaces	5	22 (22%)	4	11
Weather systems	8	1	0	9
Anti-icing	1	22 (22%)	5	8
Landing gear	5	0	3	8
Brakes	2	0	5	7
Structures	1	1	3	5
Communications	1	0	2	3
Environmental control	1	0	1	2
Miscellaneous	2	0	0	2
Navigation systems	0	0	2	2
Aircraft management	0	0	1	1
Collision avoidance system	1	0	0	1
Electrical	1	0	0	1
Furnishings and equipment	1	0	0	1
Fuel system	0	0	1	1
Total	54 (100%)	9 (100%)	43 (100%)	106 (100%)

TABLE 30.—FREQUENCY OF LOC INCIDENTS RELATED TO LANDING GEAR COMPONENTS

Landing gear component	Frequency
Nose-wheel steering	76 (21%)
Nose gear	48
Main gear	42
Antiskid system	36
Gear extend/retract mechanism	33
Landing gear	33
Main gear tire	20
Wheels/tires/brakes	14
Tail wheel	9
Gear lever/selector	8
Gear down lock	8
Nose gear tire	6
Nose gear wheel	4
Tires	4
Main gear wheel	3
Wheel assemblies	3
Nose gear door	2
Gear float	2
Gear ski	2
Gear up lock	1
Landing gear indicating system	1
Main gear door	1
Total	357

3.3.2 Brakes

Only three components were specified in brake-related incidents. The normal brake system accounted for just under half of these incidents, with brake system and parking brake accounting for the rest. (See Table 31 for actual percentages.) Since adaptive control technology is not likely to address these issues, the brake system might not be a focus of the IRAC project, but might be treated in a similar manner to landing gear.

TABLE 31.—FREQUENCY OF LOSS OF CONTROL INCIDENTS RELATED TO BRAKE COMPONENTS

Brake component	Frequency
Normal brake system	132 (55%)
Brake system	64 (27%)
Parking brake	44 (18%)
Total	240 (100%)

3.3.3 Air Flight Control

Looking into the air flight control system more in depth, the autopilot is the cause of over half of the LOC incidents (Table 32). Following this are the aeroplane flight control, autoflight system, and the flight management system/flight management computer.

TABLE 32.—FREQUENCY OF LOSS OF CONTROL (LOC) INCIDENTS RELATED TO AIR FLIGHT CONTROL SYSTEM COMPONENTS

Flight control system component	Frequency
Autopilot	104
Aeroplane flight control	35
Autoflight system	27
Flight management system/flight management computer (FMS/FMC)	20
Flight control computer (FCC)	5
Mode control panel (MCP)	4
Autoland	3
Inertial navigation system (INS) inertial reference system (IRS)/inertial reference unit (IRU)	2
Flight augmentation computer (FAC)	2
Full authority digital engine control (FADEC)/thrust control computer (TCC)	2
Flight control unit (FCU)	2
Altitude heading reference system (AHRS)/navigation display (ND)	1
Total	207

3.3.4 Propulsion Systems

The propulsion system components that contribute to LOC incidents are much more varied than the other looked at in this study as shown in Table 33. The largest contributor to incidents in the propulsion system is the throttle/power level, with just over 15 percent of propulsion-related incidents. The next largest contributors were the engine, turbine engine, reciprocating engine assembly and the speedbrake spoiler. These components make up over 50 percent of propulsion-related incidents. These components are shaded in Table 25, and a full list of components that caused incidents relating to the propulsion system is available as well.

3.3.5 Control Surfaces

The actual components listed that fall under the control surfaces aircraft system are a little less concentrated than the previous two systems as presented in Table 34. The rudder, aileron, and elevator control systems account for 44 percent of all control-surface-related LOC incidents. The various control systems may be areas of research that the IRAC project could contribute to.

TABLE 33.—FREQUENCY OF LOSS OF CONTROL INCIDENTS RELATED TO PROPULSION SYSTEM COMPONENTS

Propulsion system component	Frequency	Propulsion system component	Frequency
Throttle/power level	28 (15%)	Engine electric starter	1
Engine	23 (13%)	Engine starting system	1
Turbine engine	15	Engine torque indication	1
Reciprocating engine assembly	15	Exhaust manifold	1
Speedbrake/spoiler	13	Inverter	1
Turbine engine thrust reverser	11	Main rotor	1
Propeller blade	9	Main rotor hub	1
Rudder	9	Powerplant fuel control	1
Engine control	7	Powerplant fuel distribution	1
Thrust reverser control	4	Propeller assembly	1
Carburetor	4	Propeller brake	1
Powerplant fuel control unit	4	Propeller control	1
Propeller pitch change mechanism	4	Propeller ice system	1
Vacuum system	3	Propeller reversing	1
Carburetor heat control	3	Reverse actuator	1
Spoiler system	2	Reverser clamshell door	1
Powerplant mounting	2	Supercharger	1
Propeller	2	Switch	1
Propeller synchronization	2	Vacuum pump	1
Auxiliary engine turbine	1		
Combustor assembly	1	Total	182

TABLE 34.—FREQUENCY OF LOSS OF CONTROL INCIDENTS RELATED TO CONTROL SURFACE COMPONENTS

Control systems component	Frequency
Rudder control system	24 (17%)
Aileron control system	20 (14%)
Elevator control system	19
Elevator trim system	18
Elevator	8
Horizontal stabilizer trim	7
Trailing edge flap	6
Pitot/static ice system	5
Aileron	5
Rudder pedal	5
Trailing edge flap control	5
Elevator control column	4
Rudder trim system	4
Flap/slat control system	3
Horizontal stabilizer control	3
Aileron control column	2
Horizontal stabilizer	2
Aileron trim system	1
Elevator feel system	1
Elevator tab	1
Gust lock	1
Total	144

3.4 Aviation Safety Reporting System Data Analysis Conclusions

Of the 1463 LOC incidents for Part 91, 12, and 135 identified with a system or component problems in the ASRS database, over 210 systems or components are identified as contributing to the incident. The most frequent of these components or systems are provided in Table 35. These 24 components account for 63 percent of all LOC incidents attributed to component or system failures or malfunctions.

Looking at the analysis from a slightly higher level, five aircraft systems have been identified as critical in regards to the frequency of incidents they represent. These systems are landing gear, brakes, air flight control, propulsion systems, and control surfaces.

TABLE 35.—FREQUENCY OF THE TOP SYSTEMS OR COMPONENTS RELATED TO LOSS OF CONTROL INCIDENTS

System or component	Frequency
Normal brake system	132
Autopilot	104
Nose-wheel steering	76
Brake system	64
Nose gear	48
Parking brake	44
Main gear	42
Antiskid system	36
Aeroplane flight control	35
Gear extend/retract mechanism	33
Landing gear	33
Throttle/power level	28
Autoflight system	27
Autothrottle/speed control	26
Rudder control system	24
Engine	23
Aileron control system	20
Flight management system/flight management computer	20
Main gear tire	20
Elevator control system	19
Attitude indicator	18
Elevator trim system	18
Hydraulic main system	15
Turbine engine	15
Total	920

4.0 Adverse Conditions Table

The purpose of the adverse conditions table found in the IRAC technical plan is to provide focus to the technology validation strategy. The adverse conditions are those events that lead or contribute to LOC incidents or accidents. These adverse condition types are categorized into three types: failure, damage, and upset. The failure adverse condition is defined as a system/component that does not work properly including degradation of performance. Damage is defined as a structure or component that is broken. Upset consists of pilot error and/or LOC due to occurrences that cannot be regulated via aircraft technology.

The IRAC Systems Analysis Team has updated the initial adverse conditions table by collecting accident and incident data gleaned from findings within the ASRS, FAA, and NTSB databases. The intent was to call attention to damage conditions that occur frequently while providing insight on their severity and frequency. Primarily, the majority of the accidents were derived from the NTSB database, and the incidents were extracted from the ASRS database.

Thirteen adverse conditions subtypes of significance were found. Suggested initial test conditions are provided in the table for each of the adverse condition subtypes. The severity and frequency of each subtype is provided also as a means of prioritizing the example damage conditions. Finally, applicable IRAC milestones are referenced. Table 36 is the updated adverse conditions table.

TABLE 36.—ADVERSE TEST CONDITIONS

Adverse condition	Adverse condition subtype	Severity and frequency	Initial test conditions	Milestone references
Failure: System/ component does not work properly. Includes degradation of performance.	1. Landing gear • Nose-wheel steering • Main gear and tire • Antiskid/braking system • Gear extend/retract mechanism	Accident (1) Incident (597)	• Use of a landing gear test facility to perform dynamometer testing of aircraft wheel and brake assemblies • Structural testing on strength and fatigue of body and wing landing gear (F–15)	• Baseline F–15 adaptive control assessment/validation • IRAC 4.1.1 • Systems analysis/data mining for test condition refinement • IRAC 4.2.2 (leverages integrated vehicle health management (IVHM) data-mining expertise) • Requirements and test criteria • IRAC 2.5.2.2 Simulation evaluation of test conditions • IRAC 3.1.1.1, 3.2.1.1, and 4.1.2.1 • Full-scale F/A–18 assessment/validation • IRAC 4.1.2.2
	2. Avionics • Autopilot/flight • Flight management/monitoring system • Weather radar	Accident (1) Incident (347)	Use of flight simulators to test numerous challenges using real flight data configuration, winds, terrain, and runway info	
	3. Electrical • Auxiliary power unit • Radar • Actuator wire breaks • Wire chafing	Accident (3) Incident (25)	Physics of fault modeling at the component level and accelerated aging tests to characterize degradation	
	4. Hydraulics	Accident (0) Incident (24)	Experimental testing of monitoring approach on a representative actuator subjected to nominal and accelerated wear conditions	
	5. Static and dynamic actuator failure effects (single actuator and multiple actuator failures)	Accident (n/a) Incident (n/a)	• Locked stabilator (F–15) • Stabilator driven to local angle-of-attack (F/A–18)	
	6. Environmental Control System • Pressurization system	Accident (1) Incident (9)	Perform pressurization diagnostic tests by means of actual or simulated flight (F–15)	

TABLE 36.—Concluded.

Adverse condition	Adverse condition subtype	Severity and frequency	Initial test conditions	Milestone references
Damage: Structure/ component is broken.	7. Propulsion system • Throttle/power level system • Engine -fire -engine icing • Fuel system	Accident (20) Incident (182)	Use of an aircraft engine test facility to perform testing on all necessary components in addition to thrust measurements	• Baseline F–15 adaptive control assessment/validation • IRAC 4.1.1 • Systems analysis/data mining for test condition refinement • IRAC 4.2.2 (leverages IVHM data-mining expertise) • Requirements and test criteria • IRAC 2.5.2.2 • Simulation evaluation of test conditions • IRAC 3.1.1.1, 3.2.1.1, and 4.1.2.1 • Full-scale F/A–18 assessment/validation • IRAC 4.1.2.2
	8. Control surfaces • Rudder, aileron, and elevator	Accident (8) Incident (144)		
	9. Aerodynamic and structural damage (wing and/or tail)	Accident (1) Incident (41)	• Destabilizing angle-of-attack feedback to the canards, wing damage simulation (F–15) • Locked flaps (F/A–18)	
Upsets: Consists of pilot error and/or loss of control due to occurrences that cannot be regulated via aircraft technology.	10. Electrical	Accident (3) Incident (25)	Physics of fault modeling at the component level and accelerated aging tests to characterize degradation	• Systems analysis/data mining for test condition refinement • IRAC 4.2.2 (leverages IVHM data-mining expertise) • Requirements and test criteria • IRAC 2.5.1.1 • Simulation evaluation of test conditions • IRAC 3.1.2.1 and 3.2.2.1
	11. Severe weather • Icing • Winds • Poor evaluation of weather	Accident (56) Incident (n/a)	Analytical study of icing physics and winds; experimental testing of propulsion icing/winds in available facilities	
	12. Inadequate attitude/airspeed, and/or stall/spin	Accident (36) Incident (n/a)	• Elevated angle of arrival (pre-stall) • Stall	
	13. Pilot • Improper use of controls • Inadequate training/experience	Accident (104) Incident (n/a)	• Use of Ames Research Center's "Human Factors Research" to further investigate testing procedures	

5.0 Discussion and Conclusions

In-flight loss of control (LOC) is a serious aviation problem. Well over half of the LOC accidents included at least one fatality (81 percent in Part 121), and roughly half of all aviation fatalities in the studied time period occurred in conjunction with LOC.

In Part 121, LOC was somewhat more likely to occur during approach and landing (as opposed to takeoff or en route), but during takeoff a LOC was most likely to result in a fatality. In Part 135 flights, LOC was least likely to occur en route, although when control was lost en route in Nonscheduled Part 135 it almost always resulted in fatalities.

In about 31 percent of in-flight Part 121 LOC accidents, the LOC was secondary to a system/component failure/malfunction, compared with 8 to 12 percent of the accidents in other flight operation categories. Twenty-three percent of the in-flight Part 121 LOC accidents were secondary to aircraft damage (most often due to fire), compared with 3 to 8 percent of the accidents in other flight operation categories. As a result, for roughly 35 percent of the inflight LOC accidents in Part 121, aircraft control was not possible, compared with 6 to 9 percent of the accidents in other flight operation categories.

While the ASRS database includes over 210 components that contributed to LOC incidents in Parts 121, 135 and 91 flights, nearly 63 percent of all incidents were attributed to a component malfunction or failure related to about 24 components or systems. Five aircraft systems have been identified as critical in regards to the frequency of incidents they represent. These systems are landing gear, brakes, air flight control, propulsion systems, and control surfaces. The top five most cited systems or components in LOC incidents were normal brake system, autopilot, nose-wheel steering, brake system, and nose gear.

The adverse conditions types were categorized as failure, damage, and upset. Thirteen separate adverse conditions subtypes were found. In the "failure" category, landing gear/brakes, avionics, electrical, and hydraulic systems account for the majority of LOC incidents. The propulsion system, control surfaces, and aerodynamic and structural damage account for the majority of LOC accidents and incidents in the "damage" category, while severe weather, inadequate attitude/airspeed, stall/spin, electrical, and pilot error account for the majority of "upset" LOC accidents.

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Appendix A.—Acronyms

ACN	ASRS Incident Report Number
ARC	abnormal runway contact
AHRS	altitude heading reference system
AMAN	abrupt maneuver
ARMD	Aeronautics Research Mission Directorate
ASIAS	Aviation Safety Information Analysis and Sharing
ASRS	Aviation Safety Reporting System
ATM	air traffic management
AvSAFE	Aviation Safety Program
CAST/ICAO	Commercial Aviation Safety Team/International Civil Aviation Organization
CICTT	CAST/ICAO Common Taxonomy Team
FAA	Federal Aviation Administration
FAC	flight augmentation computer
FADEC	full authority digital engine control
FAR	Federal Aviation Regulation
FCC	flight control computer
FCU	flight control unit
F–POST	fire post impact
FMC	flight management computer
FMS	flight management system
ICE	icing
Inst/Com/Nav	instrumentation/communication/navigation
IMC	instrument meteorological conditions
INS	inertial navigation system
IRAC	Integrated Resilient Aircraft Control
IRS	inertial reference system
IRU	inertial reference unit
IVHM	integrated vehicle health management
LOC	loss of control
LOC–I	loss of control, in-flight
MCP	mode control panel
NASA	National Aeronautics and Space Administration
ND	navigation display
NTSB	National Transportation Safety Board
RAMP	ground handling
SAS	Statistical Analysis System
SCFM	system/component failure/malfunction
SCF–NP	system/component failure/malfunction, nonpowerplant
SCF–PP	system/component failure/malfunction, powerplant

TCC	thrust control computer
UNK	unknown
VFR	visual flight rules
WSTRW	windshear or thunderstorm
WX	weather

Appendix B.—In-Flight Loss of Control Accidents in Part 121 and Scheduled Part 135 Flight Operations

The tables in this appendix list the accidents in Part 121 and Scheduled Part 135 flight operations that were determined to include in-flight loss of control. In each table, the following information is provided:

- National Transportation Safety Board (NTSB) report number
- Event date
- Commercial Aviation Safety Team/International Civil Aviation Organization (CAST/ICAO) aviation occurrence categories determined for this accident
- If the accident included a system/component failure/malfunction (SCFM) of either the powerplant (SCF–PP) or non-powerplant (SCF–NP), the specific system involved is listed under "System."
- The phase of flight for the initiating event of the accident.
- The level of aircraft damage: destroyed, substantial, or minor.
- The highest degree of injury associated with the accident (fatal, serious, minor, or none), and the number of fatalities, if any.
- The primary cause for the loss of control. If the listed cause is "Not possible," then the NTSB determined that under the circumstances (usually component failure or damage), it was not possible for the pilot to maintain control of the aircraft.

Explanation of the CAST/ICAO aviation occurrence categories cited in the tables is provided below (Ref. 5).

Common Taxonomy Team Aviation Occurrence Categories Definitions found in Tables 37 to 42

AMAN (abrupt maneuver).—The intentional abrupt maneuvering of the aircraft by the flight crew
ARC (abnormal runway contract).—Any landing or takeoff involving abnormal runway or landing surface contact
ATM (ATM/CNS).—Occurrences involving air traffic management (ATM) or communications, navigation, or surveillance (CNS) service issues
F–NI (Fire/smoke (nonimpact))
F–POST (Fire/smoke (post-impact)).—Fire/smoke resulting from impact

ICE (icing).—Accumulation of snow, ice, freezing rain, or frost on aircraft surfaces that adversely affects aircraft control or performance
LALT (low-altitude operations).—Collision or near collision with obstacles/objects/terrain while intentionally operating near the surface (excludes takeoff or landing phases)
LOC–I (loss of control–in-flight).—Loss of aircraft control while or deviation from intended flight path in flight
RAMP (Ground handling).—Occurrences during (or as a result of) ground handling operations
RE (runway excursion).—A veer off or overrun off the runway surface
SCF–NP (system/component failure/malfunction (non-powerplant)).—Failure or malfunction of an aircraft system or component, other than the powerplant
SCF–PP (system/component failure/malfunction (powerplant)).—Failure or malfunction of an aircraft system component related to the powerplant
TURB (turbulence encounter).—In-flight turbulence encounter
UNK (unknown or undetermined).—Insufficient information exists to categorize the occurrence
WSTRW (windshear or thunderstorm).—Flight into windshear or thunderstorm

TABLE 37.—LOSS OF CONTROL (LOC) ACCIDENTS IN PART 121 (1988 TO 2004) FOLLOWING SCFM

NTSB report number	Event date	CAST/ICAO aviation occurrence categories	System	Phase of flight	Aircraft damage	Highest injury (fatalities)	Cause of LOC
DCA00MA026	2/16/2000	SCF–NP, LOC–I, F–POST	Flight control	Takeoff	Destroyed	Fatal (3)	Not possible
DCA03MA022	1/8/2003	SCF–NP, RAMP, LOC–I, F–POST	Flight control	Takeoff	Destroyed	Fatal (21)	Not possible
DCA00MA023	1/31/2000	SCF–NP, LOC–I	Flight control	Cruise	Destroyed	Fatal (88)	Not possible
DCA94MA076	9/8/1994	SCF–NP, LOC–I, F–POST	Flight control	Approach	Destroyed	Fatal (132)	Not possible
MIA96FA059	1/7/1996	SCF–NP, LOC–I	Landing gear	Takeoff	Substantial	Minor	Improper procedure or decision
DCA92MA022	2/15/1992	SCF–NP, LOC–I, F–POST	Inst/Com/Nav	Missed Approach	Destroyed	Fatal (4)	Spatial disorientation
DCA91MA023	3/3/1991	SCF–NP, LOC–I, F–POST	Flight control	Approach	Destroyed	Fatal (25)	Not possible
DCA89MA063	7/19/1989	SCF–PP, LOC–I, F–POST	Engine	Cruise	Destroyed	Fatal (111)	Not specified

TABLE 38.—LOSS OF CONTROL (LOC) ACCIDENTS IN PART 121 (1988 TO 2004) FOLLOWING DAMAGE

NTSB report number	Event date	CAST/ICAO accident categories	System	Phase of flight	Aircraft damage	Highest injury (fatalities)	Cause of LOC
MIA97RA011	10/22/1996	F–NI, LOC–I	None	Takeoff	Destroyed	Fatal (340)	UNK
DCA96MA054	5/11/1996	F–NI, LOC–I	None	Climb	Destroyed	Fatal (110)	Not possible
DCA96MA070	7/17/1996	F–NI, LOC–I	None	Climb	Destroyed	Fatal (230)	Not possible
DCA02MA001	11/12/2001	AMAN, SCF–NP, LOC–I, F–POST	Flight control	Takeoff	Destroyed	Fatal (265)	Not possible
MIA95RA162	6/27/1995	F–NI, LOC–I	None	Maneuver-ing	Destroyed	Fatal (2)	UNK
ANC96FA102	7/20/1996	SCF–PP, F–NI, SCF–NP, LOC–I	Engine, wing	Cruise	Destroyed	Fatal (4)	Not possible

TABLE 39.—LOSS OF CONTROL (LOC) ACCIDENTS IN PART 121 (1988 TO 2004) FOLLOWING CONTROL UPSET

NTSB report number	Event date	CAST/ICAO accident categories	System	Phase of flight	Aircraft damage	Fatalities	Cause of LOC
DCA88MA072	8/31/1988	LOC–I, F–POST	None	Takeoff	Destroyed	Fatal (14)	Improper use of controls
DCA91MA021	2/17/1991	ICE, LOC–I, F–POST	None	Takeoff	Destroyed	Fatal (2)	Inadequate ice removal
DCA92MA025	3/22/1992	ICE, LOC–I	None	Takeoff	Destroyed	Fatal (27)	Inadequate ice removal

TABLE 39.—Concluded.

NTSB report number	Event date	CAST/ICAO accident categories	System	Phase of flight	Aircraft damage	Fatalities	Cause of LOC
DCA97MA059	8/7/1997	RAMP, LOC–I, F–POST	None	Takeoff	Destroyed	Fatal (5)	Weight and balance
MIA94FA169	6/29/1994	LOC–I	None	Cruise	Minor	Serious	Control interference
DCA95MA001	10/31/1994	ICE, LOC–I	None	Maneuvering	Destroyed	Fatal (68)	Icing
DCA97MA049	5/12/1997	LOC–I	None	Descent	Minor	Serious	Airspeed/ stall
DCA01MA031	3/19/2001	ICE, LOC–I	None	Cruise	Substantial	None	Icing
CHI89MA057	3/15/1989	ICE, LOC–I, F–POST	None	Descent	Destroyed	Fatal (2)	Icing
DCA89MA035	3/18/1989	RAMP, LOC–I, F–POST	None	Takeoff	Destroyed	Fatal (2)	Inadequate preflight
DCA93RA060	8/18/1993	LOC–I, F–POST	None	Approach	Destroyed	Serious	Pilot impaired
DCA94MA065	7/2/1994	ATM, WSTRW, LOC–I, F–POST	None	Missed approach	Destroyed	Fatal (37)	Windshear

TABLE 40.—LOSS OF CONTROL (LOC) ACCIDENTS IN SCHEDULED PART 135 (1988 TO 2004) FOLLOWING SCFM

NTSB report number	Event date	CAST/ICAO accident categories	System	Phase of flight	Aircraft damage	Highest injury (fatalities)	Cause of LOC
DCA88MA059	5/24/1988	SCF–PP, LOC–I, F–POST	Engine	Takeoff	Destroyed	Serious	Improper procedure or decision
DCA91MA052	9/11/1991	SCF–NP, LOC–I, F–POST	Flight control	Descent	Destroyed	Fatal (14)	Not possible
DCA91MA033	4/5/1991	SCF–PP, LOC–I, F–POST	Propeller	Approach	Destroyed	Fatal (23)	Not possible

TABLE 41.—LOSS OF CONTROL (LOC) ACCIDENTS IN SCHEDULED PART 135 (1988 TO 2004) FOLLOWING DAMAGE

NTSB report number	Event date	CAST/ICAO accident categories	System	Phase of flight	Aircraft damage	Highest injury (fatalities)	Cause of LOC
ANC00MA125	9/18/2000	ARC, SCF–NP, LOC–I, F–POST	Landing gear	Landing	Destroyed	Fatal (5)	Airspeed or stall

TABLE 42.—LOSS OF CONTROL (LOC) ACCIDENTS IN SCHEDULED PART 135 (1988 TO 2004) FOLLOWING CONTROL UPSET

NTSB report number	Event date	CAST/ICAO accident categories	System	Phase of flight	Aircraft damage	Fatalities	Cause of LOC
DCA88MA032	2/19/1988	LOC–I, F–POST	None	Takeoff	Destroyed	Fatal (12)	Spatial disorientation
ANC90LA076	5/24/1990	LOC–I	None	Takeoff	Substantial	None	Adverse weather, winds
ANC92LA052	3/24/1992	LOC–I	None	Takeoff	Substantial	Minor	Airspeed or stall
ANC92LA057	4/2/1992	ICE, RAMP, LOC–I	None	Takeoff	Substantial	None	Inadequate ice removal
ANC92LA140	8/22/1992	LOC–I	None	Takeoff	Substantial	None	Improper procedure or decision
LAX93LA019	10/27/1992	TURB, LOC–I	None	Takeoff	Destroyed	Fatal (3)	Wake turbulence
ANC93FA034	2/20/1993	ICE, LOC–I	None	Takeoff	Destroyed	None	Inadequate ice removal
LAX93FA287	7/12/1993	RAMP, LOC–I, F–POST	None	Takeoff	Destroyed	Fatal (3)	Inadequate preflight
ANC96LA012	11/3/1995	ICE, LOC–I	None	Takeoff	Substantial	None	Inadequate ice removal
ANC98MA008	11/8/1997	ICE, RAMP, LOC–I	None	Takeoff	Destroyed	Fatal (8)	Inadequate ice removal
ANC98LA056	5/21/1998	LOC–I	None	Takeoff	Substantial	None	Premature liftoff
NYC99FA220	9/5/1999	LOC–I	None	Takeoff	Substantial	Fatal (3)	Airspeed or stall
ANC00LA021	12/24/1999	ICE, LOC–I	None	Takeoff	Substantial	Minor	Inadequate ice removal
SEA02FA002	10/3/2001	RAMP, LOC–I	None	Takeoff	Substantial	Fatal (3)	Airspeed or stall
DCA02MA003	10/10/2001	ICE, LOC–I	None	Takeoff	Destroyed	Fatal (10)	Inadequate ice removal
ANC91LA021	1/18/1991	LALT, LOC–I	None	Maneuvering	Substantial	Serious	Airspeed or stall
ANC92FA083	12/13/1991	LOC–I, F-POST	None	Cruise	Destroyed	Fatal (1)	UNK
MIA92FA067	1/23/1992	WSTRW, LOC–I	None	Descent	Destroyed	Fatal (2)	Thunderstorm
FTW93MA143	4/29/1993	ICE, LOC–I, SCF–PP, RE	Propeller	Climb	Substantial	Minor	Icing
ANC99FA047	4/14/1999	LOC–I	None	Cruise	Destroyed	Fatal (1)	Spatial disorientation
DCA90MA011	12/26/1989	ICE, ATM, LOC–I, F–POST	None	Approach	Destroyed	Fatal (6)	Icing
DCA91MA042	7/10/1991	WSTRW, LOC–I, F–POST	None	Approach	Destroyed	Fatal (13)	Thunderstorm
MIA92MA131	6/7/1992	LOC–I	None	Approach	Destroyed	Fatal (5)	Controls
DCA94MA027	1/7/1994	LOC–I, F–POST	None	Approach	Destroyed	Fatal (5)	Airspeed or stall
ANC94LA031	2/8/1994	LOC–I	None	Approach	Substantial	None	Airspeed or stall
DCA95MA006	12/13/1994	LOC–I, F–POST	None	Approach	Destroyed	Fatal (15)	Improper procedure or decision
DCA97MA017	1/9/1997	ICE, LOC–I, F–POST	None	Approach	Destroyed	Fatal (29)	Airspeed or stall
ANC00LA009	10/28/1999	ICE, LOC–I	None	Cruise	Substantial	None	Icing

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13. SUPPLEMENTARY NOTES

14. ABSTRACT
The causal factors of accidents from the National Transportation Safety Board (NTSB) database and incidents from the Federal Aviation Administration (FAA) database associated with loss of control (LOC) were examined for four types of operations (i.e., Federal Aviation Regulation Part 121, Part 135 Scheduled, Part 135 Nonscheduled, and Part 91) for the years 1988 to 2004. In-flight LOC is a serious aviation problem. Well over half of the LOC accidents included at least one fatality (80 percent in Part 121), and roughly half of all aviation fatalities in the studied time period occurred in conjunction with LOC. An adverse events table was updated to provide focus to the technology validation strategy of the Integrated Resilient Aircraft Control (IRAC) Project. The table contains three types of adverse conditions: failure, damage, and upset. Thirteen different adverse condition subtypes were gleaned from the Aviation Safety Reporting System (ASRS), the FAA Accident and Incident database, and the NTSB database. The severity and frequency of the damage conditions, initial test conditions, and milestones references are also provided.

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